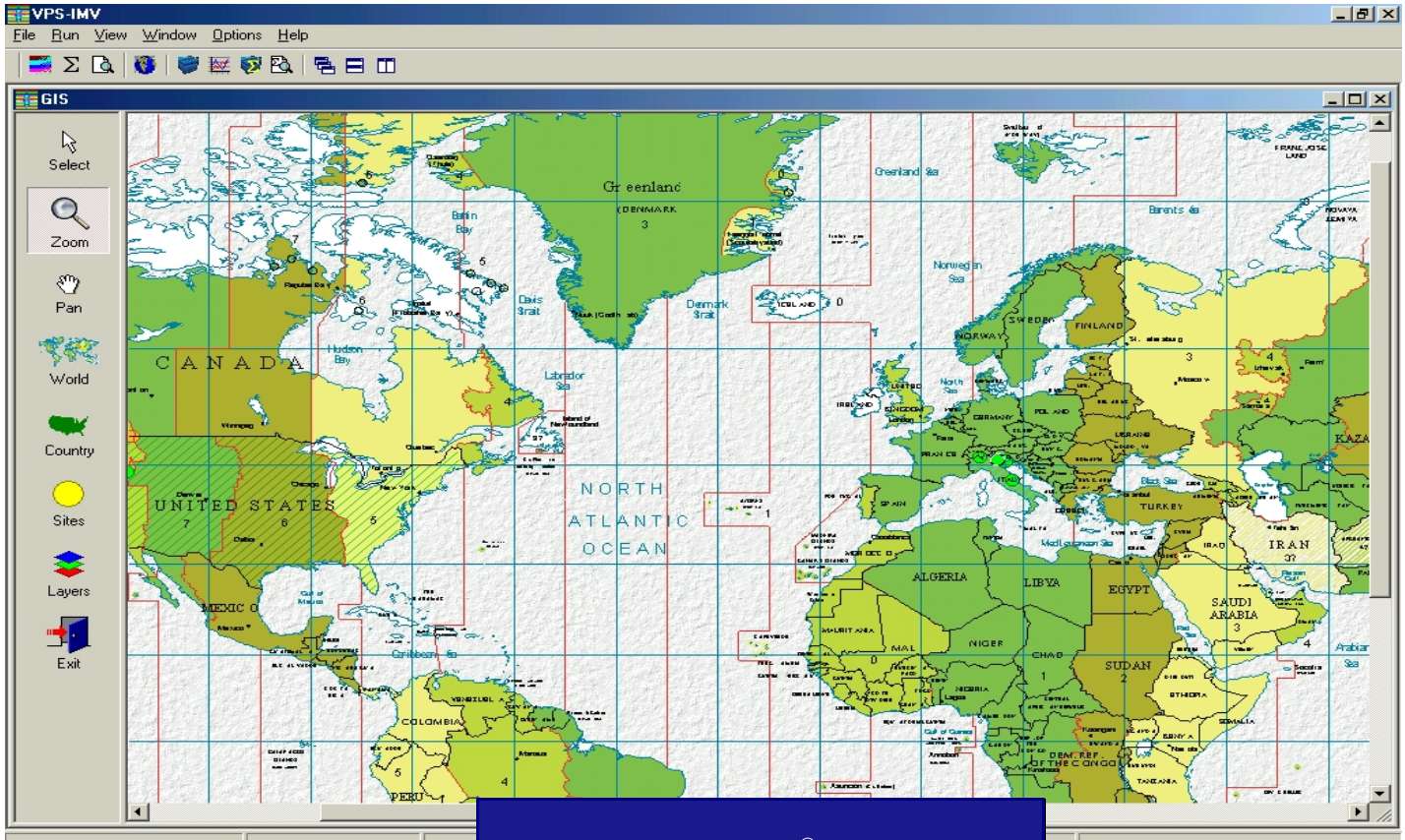
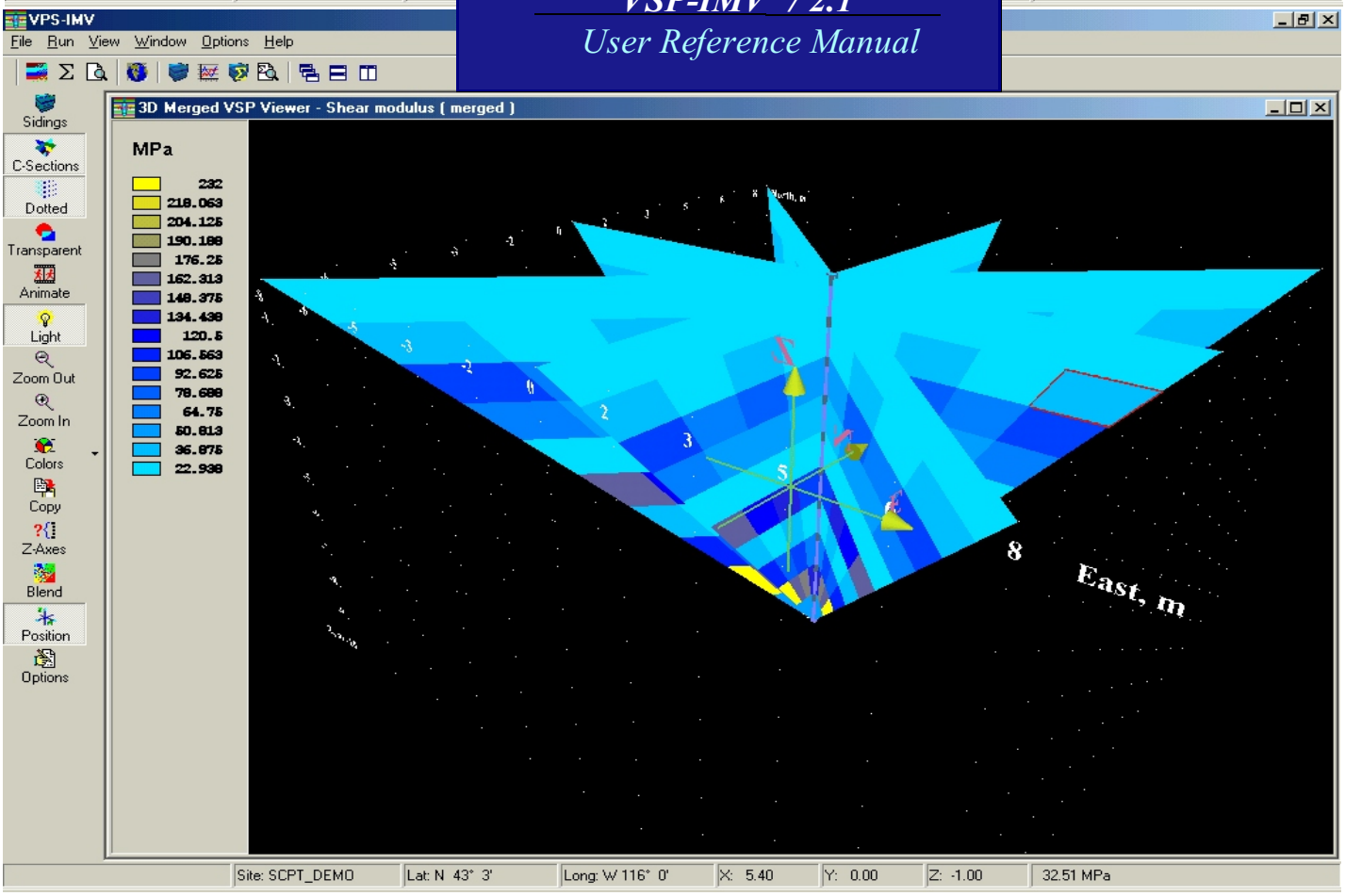


VSP-IMV® / 2.1

User Reference Manual



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1.0 Introduction

1.1 What is *VSP-IMV®*

VSP-IMV® is an advanced vertical seismic profiling (VSP) analysis software package for downhole seismic testing (DST) (e.g., seismic cone penetration testing (SCPT)) investigations. *VSP-IMV®* incorporates a geographic information system (GIS) with the ability to overlay results from SCPT and/or VSP investigations from anywhere in the world. These DST sites are linked with a highly configurable and easily accessed elastic constants databases where two dimensional (2D) and three dimensional (3D) graphical displaying of the elastic constant numerical values is readily implemented.

VSP-IMV® provides a two and three dimensional *in-situ* compression (V_p) and shear (V_s) wave velocity DST tomographic algorithm. The imaging algorithm outlined implements an already established iterative forward modeling (IFM) technique where in-situ velocity estimates are obtained for an assumed transversely isotropic stratigraphic profile. By obtaining and merging several IFM vertical seismic profiles generated from successively greater source offsets two and three dimensional tomographic images are obtained. *VSP-IMV®* stores the results from the database merging algorithm and provides attractive 2D and 3D graphical viewing utilities. *VSP-IMV®* also provides extensive chart editing, plotting, and exporting functionality. *VSP-IMV®* includes the following features:

- Extensive GIS capabilities with the option of ordering customized maps from BCE.
- Sophisticated DST database management.
- IFM algorithm provided for estimating *in-situ* V_p or V_s values from acquired seismic time series data.
- Ability to estimate elastic constant parameters when only *in-situ* V_p or V_s values are derived.
- Ability to merge several IFM profiles so that 2D and 3D tomographic images are obtained.
- Advanced and highly configurable 2D and 3D graphical viewing.
- Extensive chart editing, plotting, and exporting functionality.

1.2 Organization of users manual

The purpose of this manual is to instruct purchasers of *VSP-IMV®* in the use of the product by explaining it's structure, taking the user step by step through the program menus, and specifying the use of interactive graphics and I/O routines. Sections 2 and 3 are devoted to this goal.

Appendix 1 provides a copy of the paper entitled “Derivation of seismic cone interval velocities utilizing forward modeling and the downhill simplex method”. This paper outlines the mathematical algorithms utilized in the IFM algorithm. Appendix 2 provides a copy of the paper entitled “Two and three dimensional imaging utilizing the seismic cone penetrometer”. This paper outlines the mathematical algorithms utilized in merging the IFM so that 2D and 3D tomographic images are obtained. Appendix 3 outlines the arrival times and probe depths specified for the example database provided with the installation software. The same example database is utilized for *Sites* Idaho, Torino, Parma, Bologna and Roma.

2.0 Program Structure

2.1 Main Menu

VSP-IMV® is Windows based program utilizing and implementing GIS, iterative forward modeling, sophisticated database management, and database merging for 2D and 3D imaging for the purpose of managing, processing, and visualizing V_p and V_s parameters acquired in DST. The main graphical interface window for *VSP-IMV®* is illustrated in Figure 1. The main menu displays several user options which relate to creating databases, carrying out IFM, database merging, 2D and 3D visualization, 2D plotting, and GIS visualization.

The first step, in most circumstances, will be for the user to configure the DST *VSP-IMV®* database.

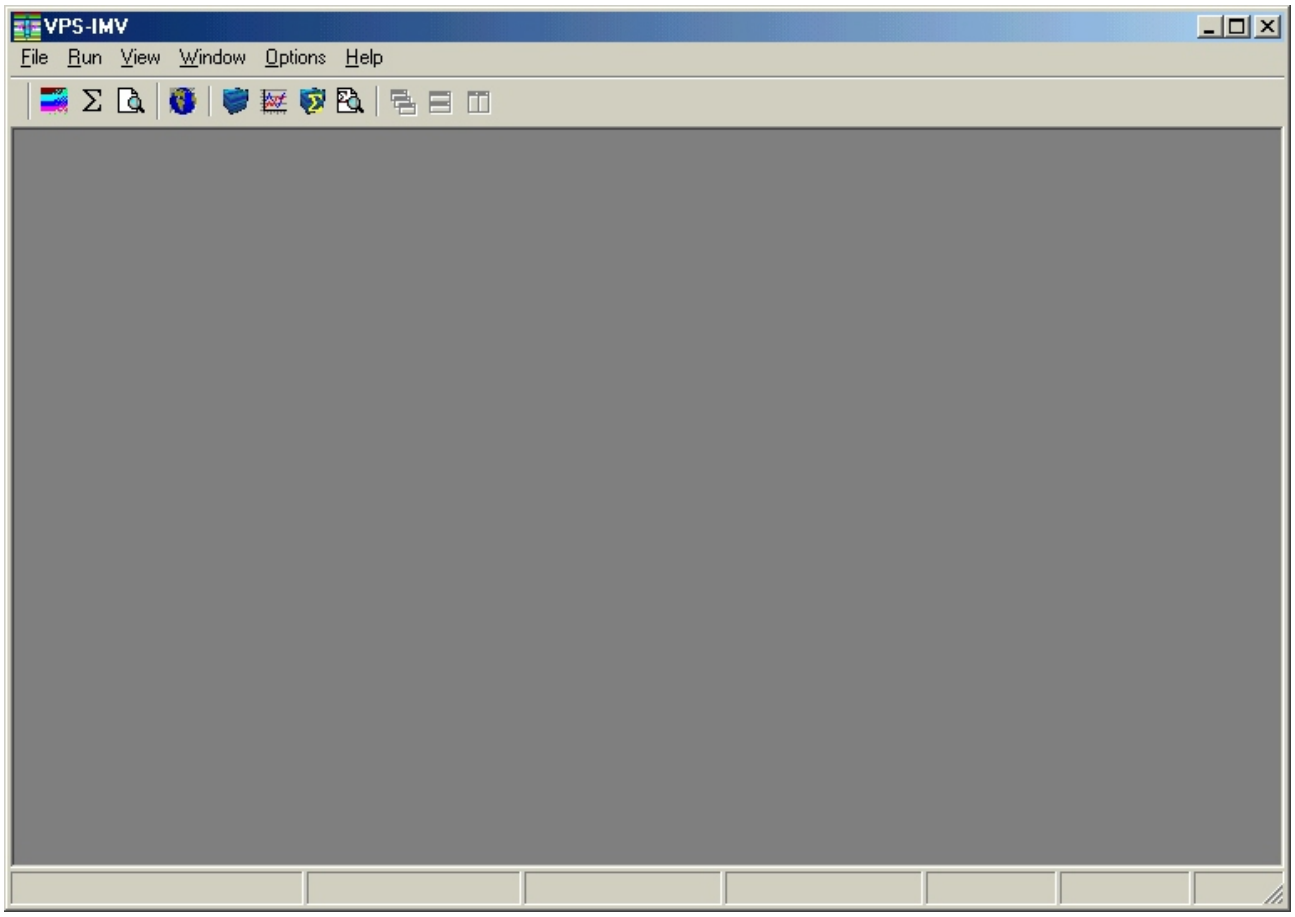


Figure 1. Main graphical user interface window in *VSP-IMV®*.

2.2 Database Creation and Management

The DST database creation and management utilities provided for in *VSP-IMV®* are designed to reflect the mathematical algorithms outlined in Appendices 1 and 2. The IFM algorithm presented in Appendix 1 is referred to by the acronym FMDSM. The FMDSM technique is expanded upon in Section 2.3.

2.2.1 Technical Background

The methodology implemented in obtaining two and three dimensional tomographic images relies upon merging several FMDSM cross-section profiles. For example, Figure 2 illustrates a plan view of a DST investigation where we have several seismic sources positioned symmetrically around the downhole seismic probe.

The generation of the seismic source waves is initiated as the seismic probe is incrementally lowered into the ground. Several FMDSM cross-section profiles are obtained from the multiple source waves recorded at each seismic probe depth increment. The optimal interval velocity estimates for each of these FMDSM cross-sections is obtained by assuming a transversely isotropic medium. Two dimensional tomographic images are derived by merging sets of FMDSM cross-sections which have similar source offset bearings as is shown in Figure 2 (e.g., $S3_1$, $S3_2$, and $SC3_3$).

Figure 3 illustrates a schematic of the parameters defining the 2D FMDSM merging algorithm. Any vertical variations in the interval velocities for a set of FMDSM cross-sections derived from source offsets with identical bearing is assumed to be due to lateral variations in the stratigraphic profile. This is due to the fact that the FMDSM algorithm provides optimal estimates for a transversely isotropic stratigraphic profile.

.

In Figure 3 the two dimensional array V2D defines elements of the estimated 2D tomographic image while array V identifies the estimated FMDSM interval velocities. X[1..m] is the associated source offsets for a constant bearing, Z[1..n] is an array which defines the incremental depth locations of the seismic probe and parameter l[1..n,1..m] is the average width for each cell within the V2D array. Since the DST is a vertical seismic profile, the 3D profiles derived have a cone surface with triangular cross-sections for each bearing line as illustrated in Figure 3.

The first column of the V2D array (i.e., [1..n, 1]) is set to the first FMDSM profile (i.e., For i := 1 to n do V2D[i,1] := V[i,1]). This is due the fact that there is only one FMDSM profile to average. All subsequent V2D cell values are derived by using a

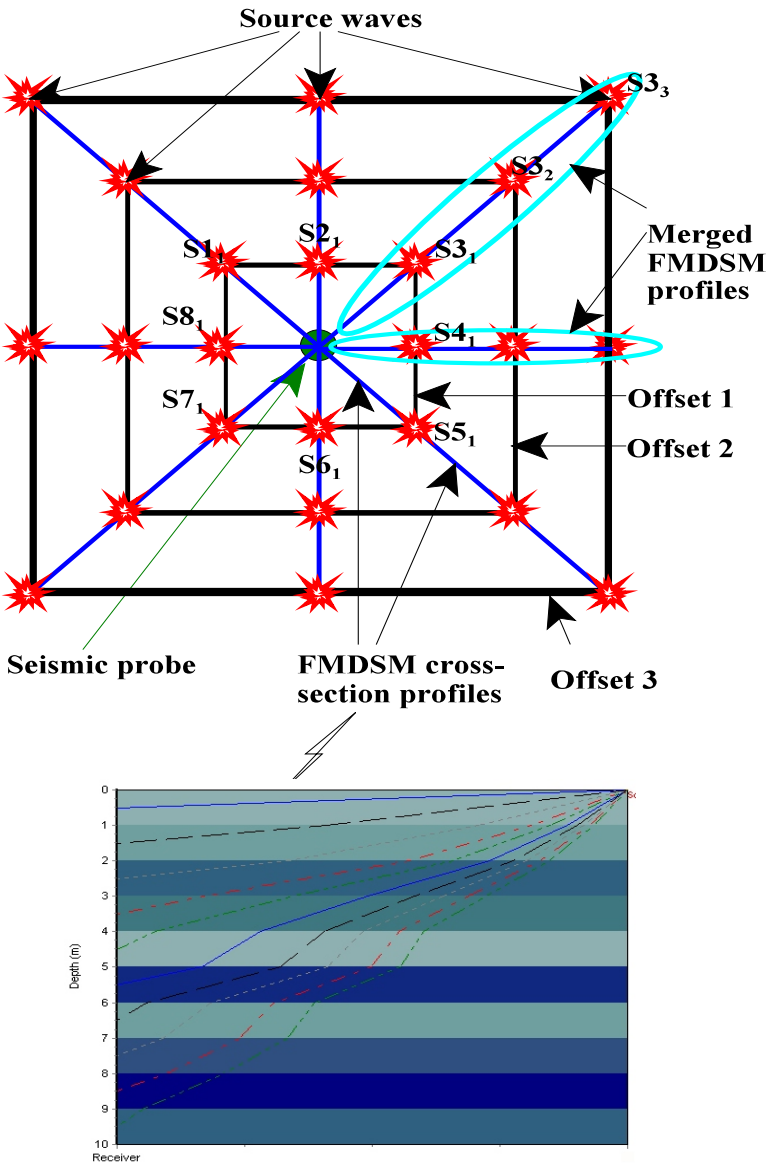


Figure 2. Schematic illustrating the DST testing configuration for generating 2D and 3D tomographic images.

linear averaging technique. For example, the value of element V2D[1,2] is obtained as follows:

$$V2D[1,2] := ((l1+l2)*V[1,2] - l1*V2D[1,1])/l2 \quad (1)$$

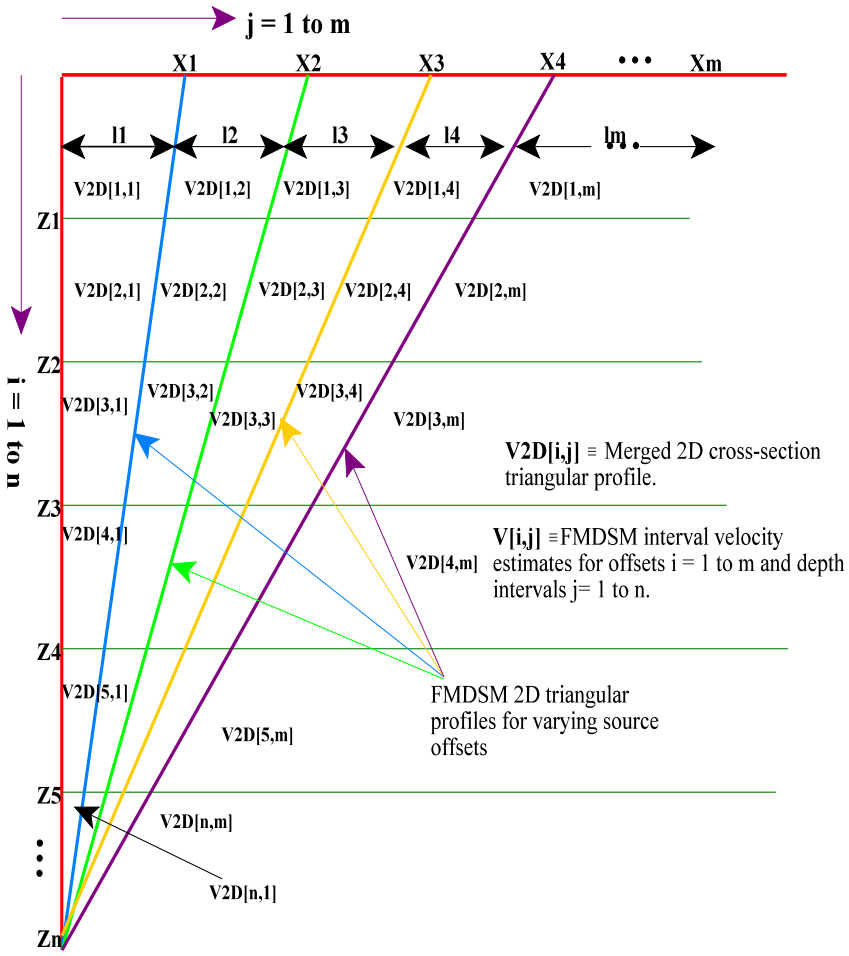


Figure 3. Schematic illustrating the 2D FMDSM merging algorithm.

2.2.2 Main *VSP-IMV®* Database Structure

The *VSP-IMV®* database structure is designed to facilitate the previously described merging of the FMDSM cross-section profiles into 2D and 3D tomographic images. Figure 4 illustrates a schematic which outlines the basic data structure for the *VSP-IMV®* software package. In Figure 4, the SCSite.db database contains the DST positional ***Site*** information of latitude and longitude. The database structure has terminology associated with a SCPT (e.g., seismic cone (SC)), but it is applicable to any DST investigation. Each ***Site*** has associated ***Cone Pushes*** that have attributes stored within the SCPush.db database. Each ***Cone Push*** identifies the *SC probe* or borehole and it has associated FMDSM profiles (SCProfiles.db) for each source offset (SCOffset.db) as illustrated in Figure 2. Each FMDSM profile has associated databases (SCVP.db/SCVS.db) for the *in-situ* estimates of V_p and V_s and finally there is a linked elastic constants database (SCEC.db) which is derived from the estimated V_p and V_s values or specification of Poisson's ratio. In the example shown in Figure 2, the seismic cone push has eight FMSDM profiles for each source offset resulting in a total of 24 FMDSM profiles (ie., 3 (source offsets) x 8 (FMDSM profiles)).

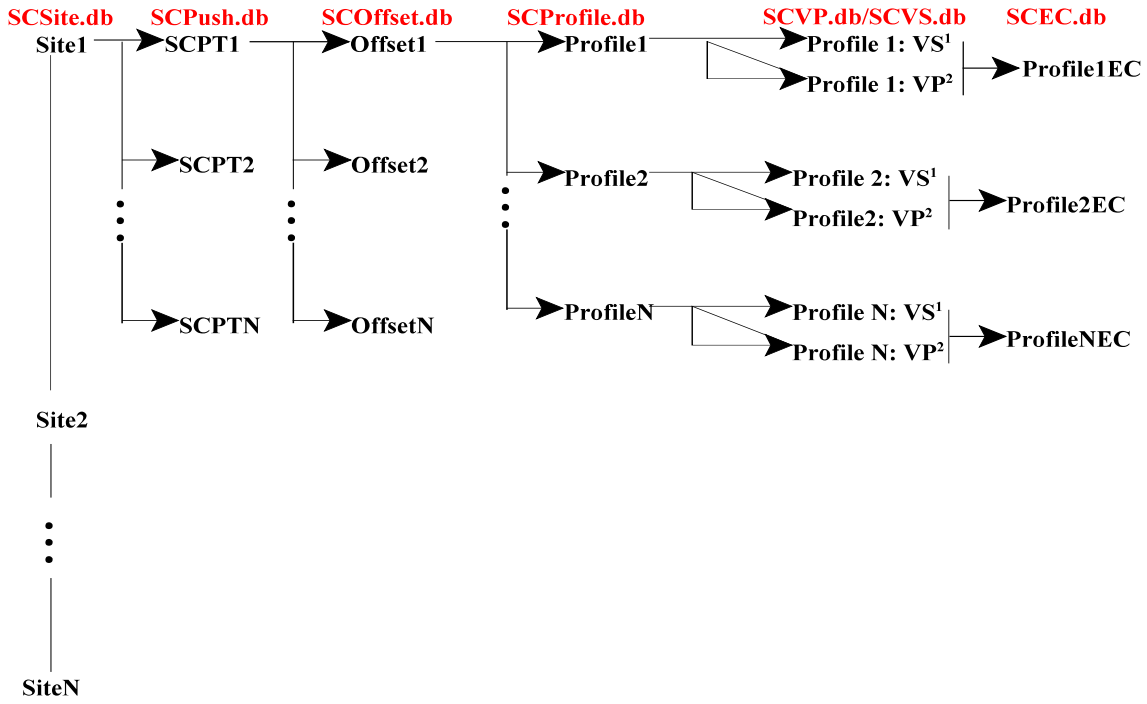


Figure 4. Schematic illustrating the basic data structure for the *VSP-IMV®* software package.

2.2.2.1 Site Configuration

The first step in configuring the DST database is for the user to select sub-menu *Options->Country List*. The user interface for *Country List* is shown in Figure 5(a). The user populates the Countries and associated States/Provinces in which DST investigations have been or will be carried out within the *Country List* database. For example, in Figure 5(a) the countries USA and Italy have been specified with the provinces of Emilia Romagna, Lazio, Sicilia, and Piemonte entered for Italy. The user adds new countries by selecting push button *Add* and typing in the appropriate country name as is shown in Figure 5(b). The same procedure is utilized in specifying the corresponding State/Province entries. An entry is deleted by pressing the *Delete* push buttons.

Once the appropriate Countries and States/Provinces have been entered into the *Country List* database, the user can begin to populate the main DST database. The main *VSP-IMV®* interface for configuring DST sites and associated cone pushes and/or boreholes, FMDSM profile and elastic constants databases is shown in Figure 6. This interface is enabled by either selecting sub-menu *Options->Edit Databases* or by selecting the icon from the toolbar illustrated in the main *VSP-IMV®* interface window.

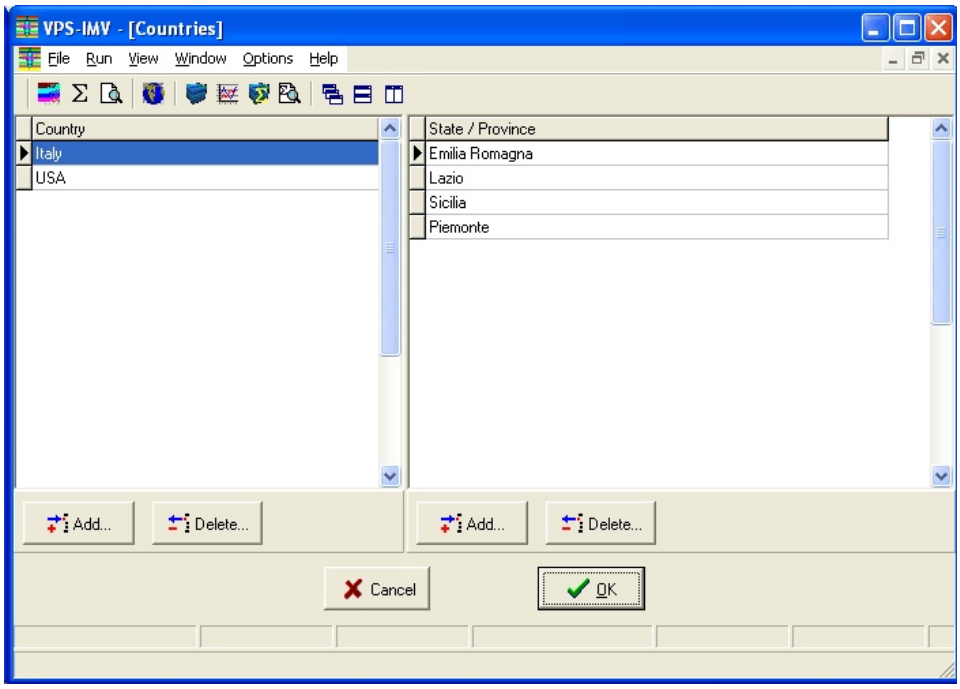


Figure 5(a). *Countries List* database user interface.

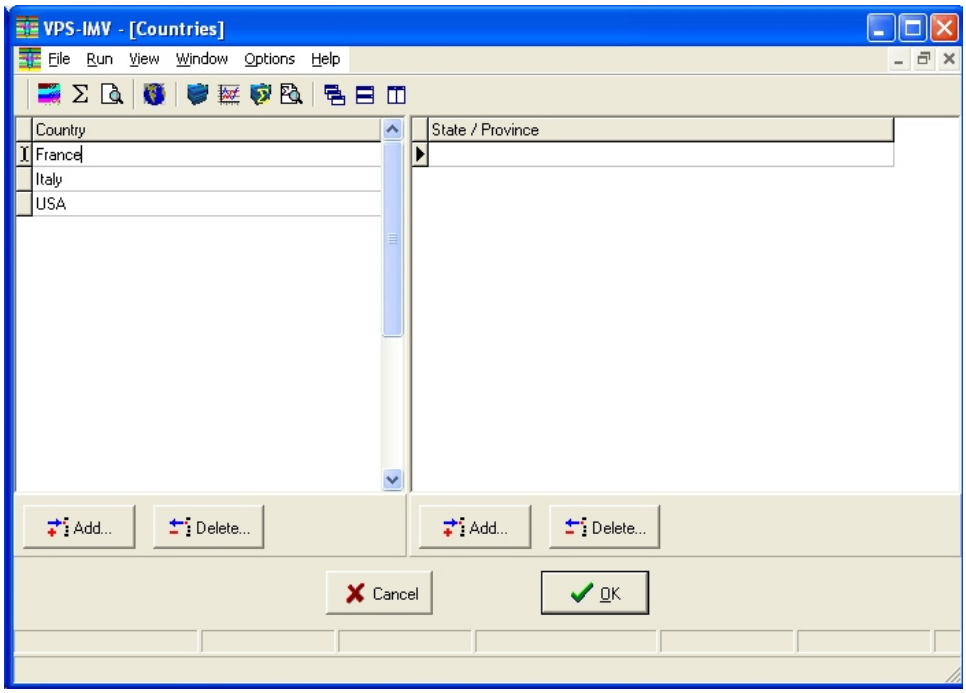


Figure 5(b). Adding a new country in the *Countries List* database.

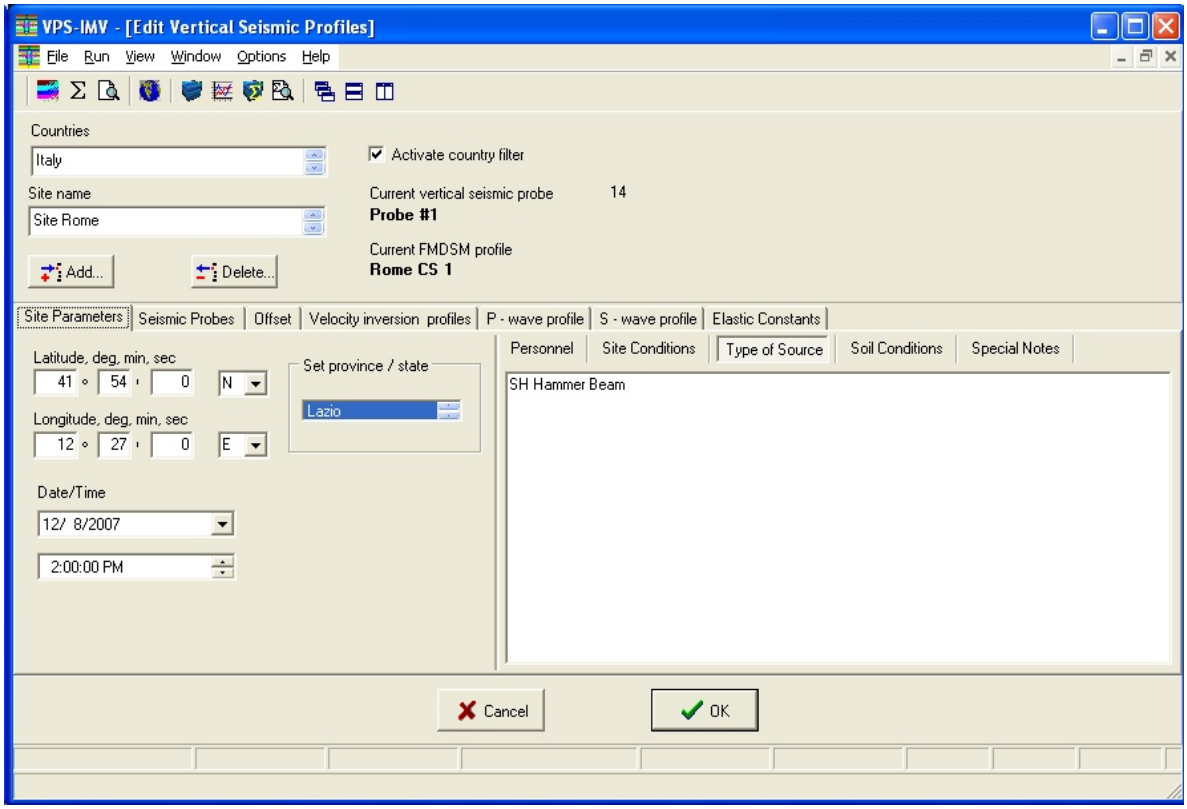


Figure 6. Main *VSP-IMV®* user interface for site configuration database.

The first step in configuring a new site for a particular country and province is for the user to populate the *Site Parameters* tab (ie., SCSite.db) as follows:

- Select the *Site Parameters* tab.
- Enable check box *Activate country filter*[1].
- Select appropriate country (*Countries*). The country list were previously specified via sub-menu *Options-> Country List*.
- Select *Add.*. push button and type in an appropriate *Site Name*.
- Highlight corresponding *State/Province*.
- Enter site positional information within the *Latitude* and *Longitude* interface boxes.
- Specify corresponding *Data/Time* when investigation occurred.
- Enter any relevant site information within the *Personnel*, *Site Conditions*, *Type of Source*, and *Special Notes* text boxes.
- Select push button *OK*.

2.2.2.2 Seismic Probes Configuration

Once a DST investigation has occurred, the user must then conFigure database tabs *Seismic Probes*, *Offset*, *Velocity inversion profiles*, *P-wave profile*, *S-wave profile* and *Elastic Constants*. These user interface tabs correspond to the previously outlined databases of SCPush.db, SCOffset.db, SCProfiles.db, SCVP.db, SCVS.db and SCEC.db, respectively. The user interface for the *Seismic Probes* tab is shown in Figure 7. The *Seismic Probes* parameters are conFigure d as follows:

1

When enabled the check box *Activate country filter* synchronizes the display of the country and corresponding sites and provinces. This is advantageous if the user prefers that only the sites which are associated with a particular country be displayed.

- Enable check box *Activate country filter*.
- Select appropriate country (*Countries*) and *Site Name*.
- Select the *Seismic Probes* tab.
- Select *Add..* push button and type in an appropriate *Seismic Probe Name*.
- Enter seismic probe positional information within the *Latitude* and *Longitude* interface boxes.
- Select push button *OK*.

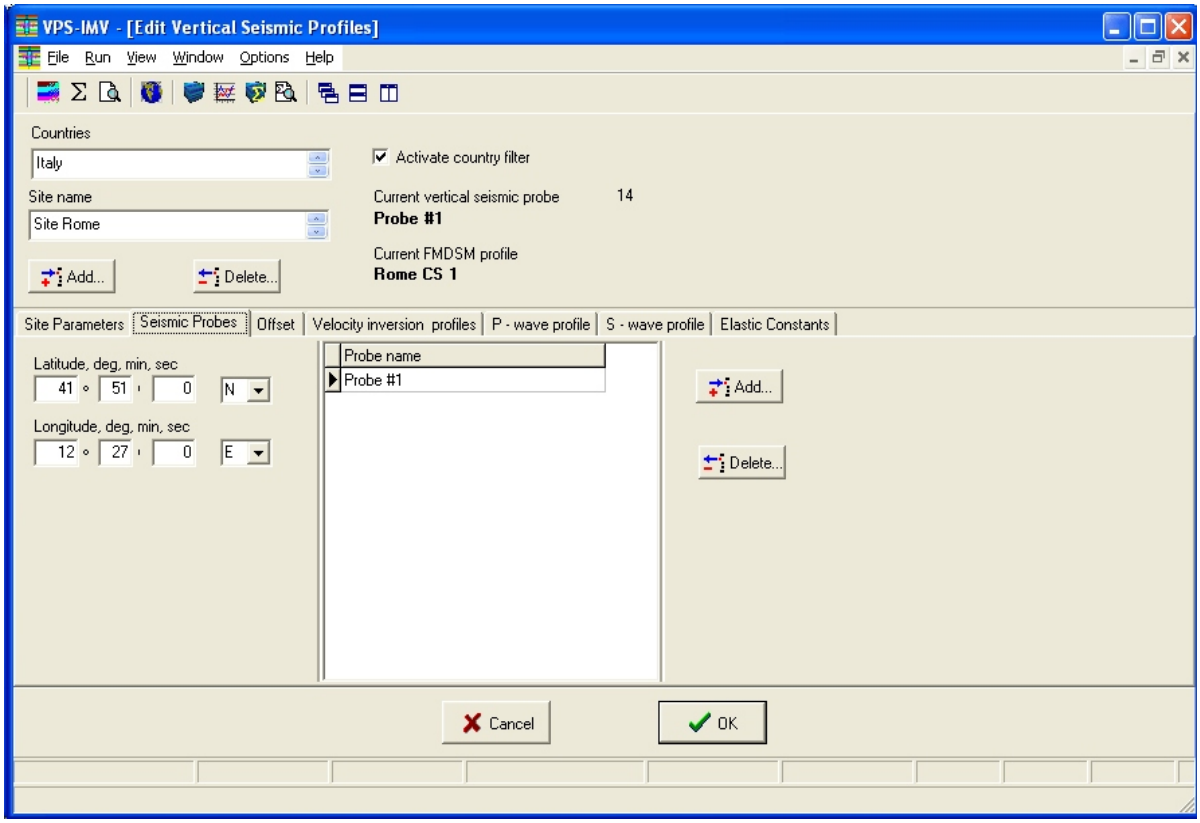


Figure 7. *Seismic Probes* user interface tab.

2.2.2.3 Offset Configuration

The *Offset* user interface tab is shown in Figure 8 and the corresponding parameters are configured as follows:

- Enable check box *Activate country filter*.
- Select appropriate country (*Countries*) and *Site Name*.
- Select the appropriate *Probe name* from the *Seismic Probes* tab.
- Select the *Offset* tab.
- Select *Add..* push button in the *Offset* interface tab and type in an appropriate *Offset name*[2].
- Repeat the above Offset configuration steps until all offsets have been specified.
- Select push button *OK*.

[2]As outlined in Figure 2, each *Offset* has associated a set of FMDSM profiles. FMDSM profiles which have a common source offset bearing are to be merged into a 2D tomographic image.

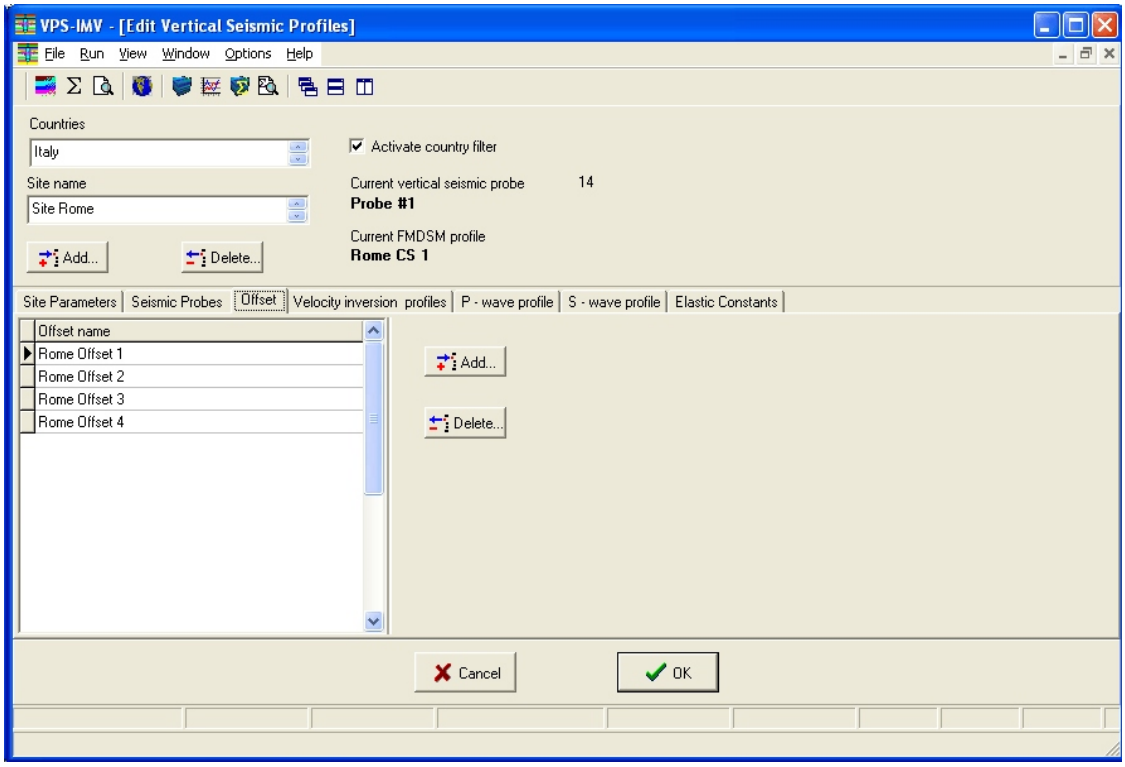


Figure 8. *Offset* user interface tab.

2.2.2.4 Velocity Inversion Profiles Configuration

The *Velocity Inversion Profiles* user interface tab is shown in Figure 9 and it corresponds to the SCProfiles.db database where a set of FMDSM profiles are linked to a specific Offset as was illustrated in Figure 2. For example, in Figure 2 seismic sources (and subsequent FMDSM profiles) **$S1_1$**, **$S2_1$**, **$S3_1$**, **$S4_1$**, **$S5_1$**, **$S6_1$**, **$S7_1$**, and **$S8_1$** are associated with **Offset 1**. The *Velocity Inversion Profiles* corresponding parameters are conFigure d as follows:

- Enable check box *Activate country filter*.
- Select appropriate country (*Countries*) and *Site Name*.
- Select the appropriate *Probe name* from the *Seismic Probes* tab.
- Select the appropriate *Offset name* from the *Offset* tab.
- Select the *Velocity inversion profiles* tab.
- Select *Add..* push button in the *Velocity inversion profiles* interface tab and type in an appropriate *Cross-section or FMDSM name*.
- Enter corresponding source east and north offset (meters) from seismic probe.
- Repeat the above *Velocity inversion profiles* configuration steps until all FMDSM profiles for the selected *Offset* have been specified.
- Select push button *OK*.

The configuration of the *P-wave Profiles* and *S-wave Profiles* databases is outlined in Section 2.3 where the FMDSM user interface is explained in detail.

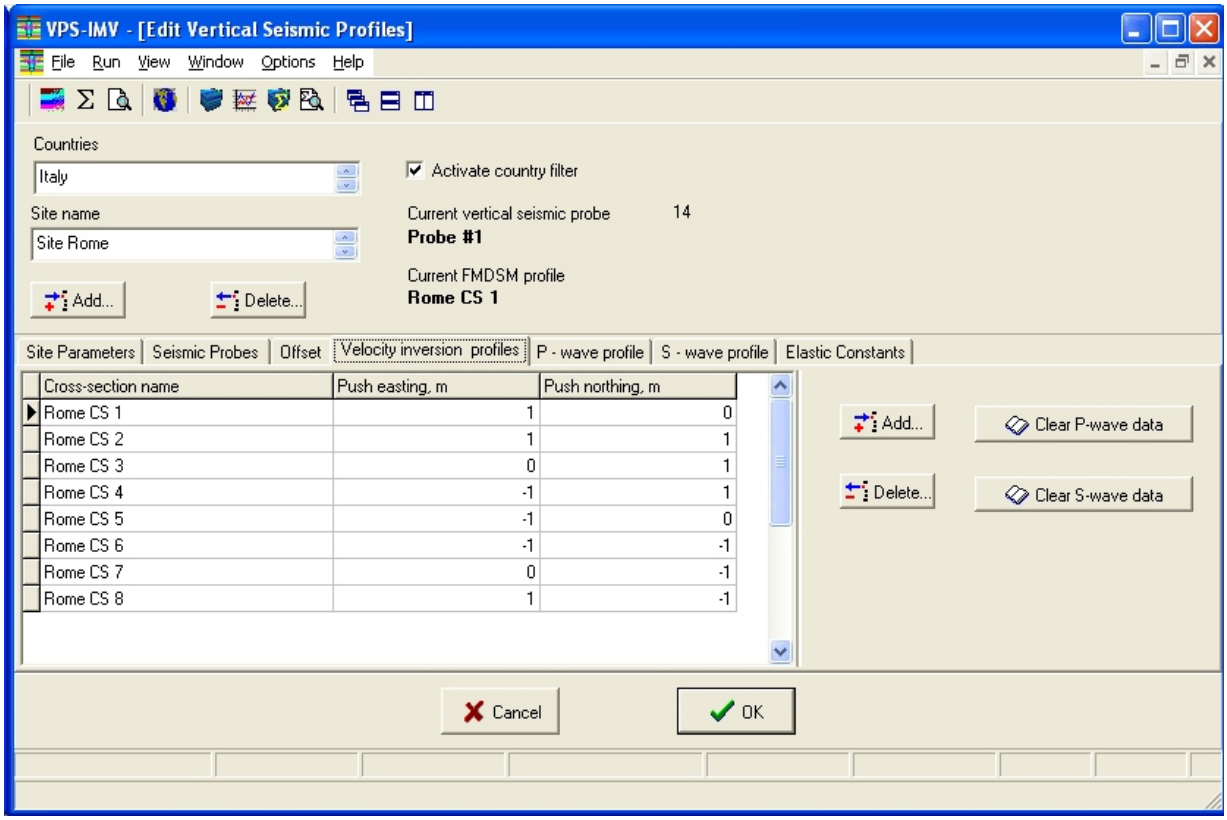


Figure 9. *Velocity inversion* profile user interface tab.

Important Database Configuration Notes:

When configuring a ***VSP-IMV®*** database it is mandatory that there is consistency when specifying the *Velocity inversion profiles* for each *Offset*. This allows for proper 3D viewing. Referring to Figure 2, the following three related items must be adhered to:

1. All *Velocity inversion profiles* must be specified in the same order. For example, if Offset #1 *Velocity inversion profiles* start in the North-West corner and are specified in counter clockwise order (CCW), then all other *Velocity inversion profiles* must be specified in the same fashion for the current *Seismic Probe* and corresponding *Offset* (i.e., *Velocity inversion profile* #1 of Offset #2 sits in the NW corner and all subsequent *Velocity inversion profiles* are specified in CCW order).

2. It is mandatory that all specified *Offsets* and their corresponding *Velocity inversion profiles* are synchronized with one another. For example, referring to Figure 2 *Offset 1 -> Velocity Inversion profile 3* (**$SC3_1$**) should be specified in the same order in the *Velocity inversion profiles* list (i.e., third down from the top of the list) as *Offset 2 -> Velocity Inversion profile 3* (**$SC3_2$**). This allows for the automation of the database merging algorithm which is subsequently outlined in Section 2.2.3.

3. For proper 3D vieiwing The ***VSP-IMV®*** database requires that the same number of *Velocity inversion profiles* be specified for each *Offset*. For example, if Offset #1 has 2/3/4...*Velocity inversion profiles* then Offsets #2..N require 2/3/4...*Velocity inversion profiles.*

2.2.2.5 VSP-IMV® Elastic Constants Database Configuration

Accurate in-situ P-wave and S-wave velocity profiles are essential in geotechnical foundation designs. These parameters are used in both static and dynamic soil analysis where the elastic constants are input variables into the models defining the different states of deformations such as elastic, elasto-plastic, and failure (Finn (1984)). Equation (2) illustrates the relationship between the elastic constants of Poisson's Ratio, Shear Modulus, Young's Modulus, and Bulk Modulus with V_p and V_s.

$$\begin{aligned} \sigma &= ((V_p/V_s)^2 - 2))/(2(V_p/V_s)^2 - 2) \\ G_0 &= \rho V_s^2 \\ E &= 2G_0(1+\sigma) \\ k &= E/(3(1-2\sigma)) \end{aligned} \qquad (2)$$

In eq. (2), σ is Poisson's ratio, G_0 is the shear modulus, E is Young's modulus, ρ is the soil denisty, and k is the bulk modulus. Some static soil analysis techniques include displacements from line loads (ie., f(E,ν)), one dimensional consolidation settlement (ie., f(m_v) where $m_v = 1/B$), and soil-structure interaction problems (ie., f(E,ν, and B)). The associated methods of response in dynamic soil analysis are the linear method (linear elastic model), equivalent linear method (visco-elastic model), and step-by-step integration method (load history tracing). All the dynamic analysis programs require accurate input parameters of shear modulus, bulk modulus, Young's modulus, and attenuation (Q value). Dynamic analysis in geotechnical practice is intimately related to the capability of measuring the necessary soil properties.

Another important use of estimated shear wave velocities in geotechnical design is in the liquefaction assessment of soils. As stated by Andrus et al. (1999), "predicting the liquefaction resistance of soil is an important step in the engineering design of new structures and the retrofit of existing structures in earthquake prone regions". Since the shear wave velocity is influenced by many of the variables that influence liquefaction (ge., void ratio, soil density, confining stress, stress history, and geologic age), it is an excellent index of liquefaction.

It is evident from eq. (2) that if the investigator can derive in-situ estimates of V_p and V_s then the associated in-situ estimates of the elastic constants can also be obtained. Table 1 outlines the relations between the elastic constants where the variable λ is defined to be Lamé's constant.

Table 1. Relations between elastic constants.

	E	**σ**	**k**	**Go**	**λ**
(E,σ)			E/(3(1-2σ))	E/(2(1+σ))	Eσ/((1+σ)(1-2σ))
(E,k)		(3k-E)/6k		3kE/(9k-E)	3k(3k-E)/(9k-E)
(E,Go)		(E-2Go)/2Go	GoE/(3(3Go-E))		Go(E-2Go)/(3Go-E)
(σ,k)	3k(1-2σ)			3k(1-2σ)/(2(1+σ))	3kσ/(1+σ)
(σ,Go)	2Go(1+σ)		2Go(1+σ)/3(1-2σ)		2Goσ/(1-2σ)
(σ,λ)	λ(1+σ)(1-2σ)/σ		λ(1+σ)/3σ	λ(1-2σ)/2σ	
(k,Go)	9kGo/(3k+Go)	(3k-2Go)/(2(3k+Go))			k-2Go/3
(k,λ)	9k(k-λ)/(3k-λ)	λ/(3k-λ)		3(k-λ)/2	
(Go,λ)	Go(3λ+2Go)/(λ+Go)	λ/(2(λ+Go))	λ + 2Go/3		

For DST investigations where only in-situ interval values of V_s or V_p are obtain, the investigator can obtain estimates of the unknown interval V_s or V_p velocities and the corresponding elastic constants by specification of interval Poisson's ratio and soil density σ values. The relation between V_s and V_p, with known σ is given as

$$V_P^2 = \frac{2(1-\sigma)}{(1-2\sigma)} V_S^2 \tag{3}$$

Values for Poisson's ratio are typically 0.25 in igneous rock, 0.33 in sedimentary rock, and 0.10-0.49 in soils (Mooney (1977)).

Figure 10 shows the user interface for the Elastic Constants database (SCEC.db) which is associated with a specific velocity inversion profile. In the Elastic Constants database the previously derived (FMDSM technique) interval V_p and/or V_s values are populated within the Elastic Constants database under headings P-velocity (average (m/s)) and S-velocity (average (m/s)). The corresponding Possion's ratio values are automatically calculated and displayed if both V_p and V_s values were derived. Alternatively, the user could specify appropriate Poisson's ratio values if only V_p or V_s values were derived. From eq. (3) the corresponding unknown V_p or V_s interval values are then calculated. The user then specifies appropriate Soil Density (Kg/m³) values and all subsequent elastic constants are automatically calculated according to eq. (2) and Table 1.

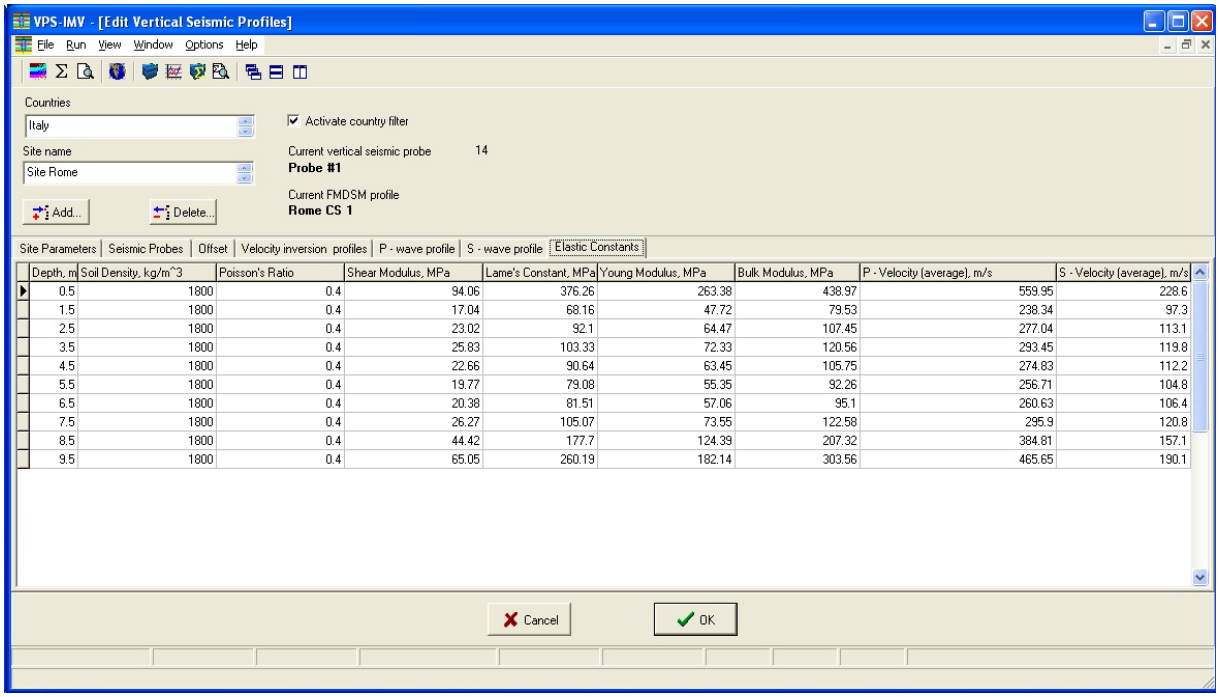

VPS-IMV - [Edit Vertical Seismic Profiles]
File Run View Window Options Help
Countries
Italy
Activate country filter
Site name
Site Rome
Current vertical seismic probe 14
Probe #1
Current FMDSM profile
Rome CS 1
Add...
Delete...
Site Parameters | Seismic Probes | Offset | Velocity inversion profiles | P - wave profile | S - wave profile | Elastic Constants
Depth, m | Soil Density, kg/m^3 | Poisson's Ratio | Shear Modulus, MPa | Lame's Constant, MPa | Young Modulus, MPa | Bulk Modulus, MPa | P - Velocity (average), m/s | S - Velocity (average), m/s
0.5 | 1800 | 0.4 | 94.06 | 376.26 | 263.38 | 438.97 | 559.95 | 228.6
1.5 | 1800 | 0.4 | 17.04 | 68.16 | 47.72 | 79.53 | 238.34 | 97.3
2.5 | 1800 | 0.4 | 23.02 | 92.1 | 64.47 | 107.45 | 277.04 | 113.1
3.5 | 1800 | 0.4 | 25.83 | 103.33 | 72.33 | 120.56 | 293.45 | 119.8
4.5 | 1800 | 0.4 | 22.66 | 90.64 | 63.45 | 105.75 | 274.83 | 112.2
5.5 | 1800 | 0.4 | 19.77 | 79.08 | 55.35 | 92.26 | 256.71 | 104.8
6.5 | 1800 | 0.4 | 20.38 | 81.51 | 57.06 | 95.1 | 260.63 | 106.4
7.5 | 1800 | 0.4 | 26.27 | 105.07 | 73.55 | 122.58 | 295.9 | 120.8
8.5 | 1800 | 0.4 | 44.42 | 177.7 | 124.39 | 207.32 | 384.81 | 157.1
9.5 | 1800 | 0.4 | 65.05 | 260.19 | 182.14 | 303.56 | 465.65 | 190.1
Cancel
OK

Figure 10. *Elastic Constants* user interface tab.

2.2.3 VSP-IMV® Database Merging for 2D and 3D Imaging

As was previously stated in Section 2.2.1, two dimensional tomographic images are derived by merging sets of FMDSM cross-sections which have similar source offset bearings as was shown in Figure 2 (e.g., $S3_1$, $S3_2$, and $SC3_3$). In addition, Section 2.2.2.4 outlined that it was mandatory that all specified Offsets and their corresponding Velocity inversion profiles are synchronized with one another. For example, referring to Figure 2 Offset 1 -> Velocity Inversion profile 3 (**$SC3_1$**) should be specified in the same order in the Velocity inversion profiles list (i.e., third down from the top of the list) as Offset 2 -> Velocity Inversion profile 3 (**$SC3_2$**). This allows for the automation of the database merging algorithm.

The user interface for merging the FMDSM profiles into 2D tomographic images is enabled by either selecting sub-menu Run->Merge elastic constants or by selecting the icon from the toolbar illustrated in the main VSP-IMV® interface window. Figure 11 illustrates the FMDSM database merging user interface.

The steps in merging the Velocity Inversion Profiles are outlined as follows:

- Select appropriate country (Countries) and Site Name.
- Select the desired Probes name from the Probes column.
- Select the desired elastic constant parameter to be merged from the Parameter column.
- Select push button Merge. The message box shown in Figure 12 appears after a successful merge.
- Repeat the above steps until all the desired elastic constants have been merged.

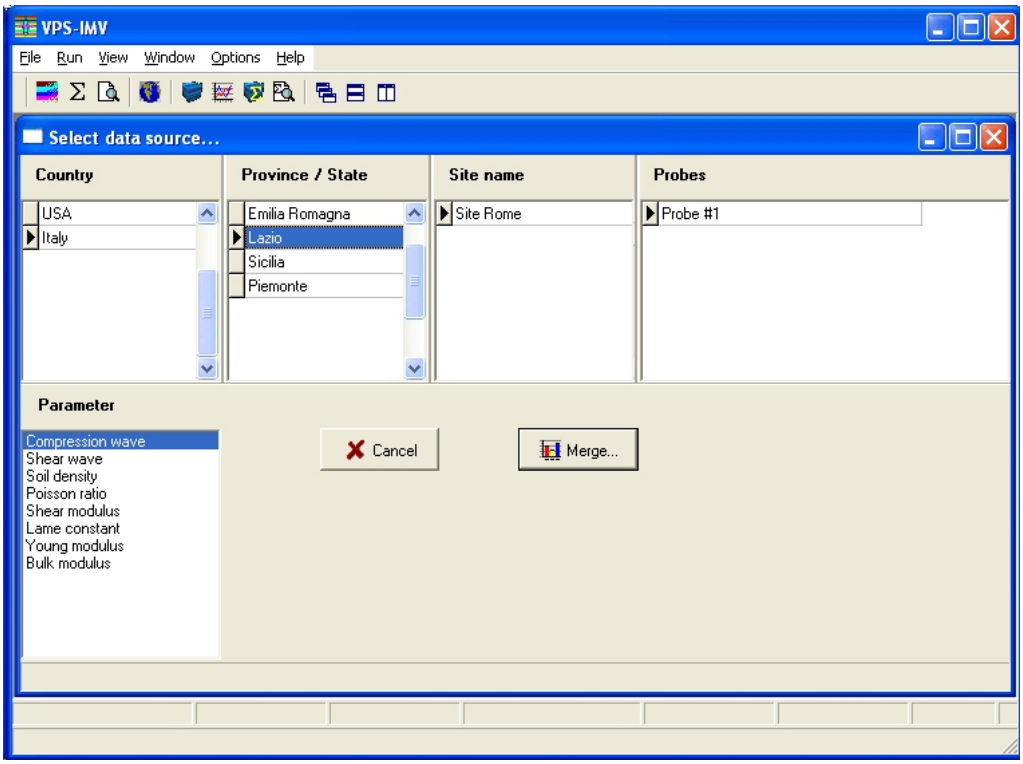
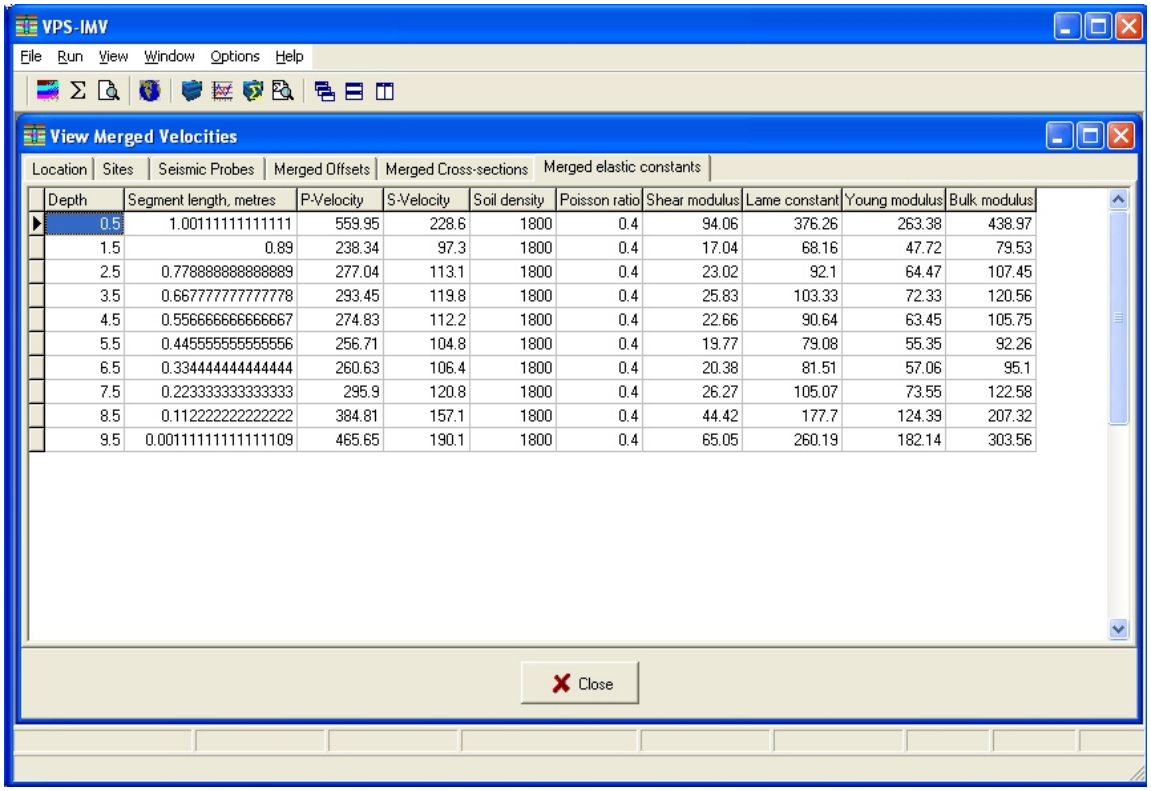


Figure 11. Database merging user interface.

Figure 12. Output message window notifying successful merging of V_p interval values.

The output results of merging the FMDSM databases can be viewed by selecting sub-menu View->View merged data or by selecting the icon from the toolbar illustrated in the main VSP-IMV® interface window. Figure 13 illustrates the user interface and related database for viewing the results of merging the FMDSM cross-sections.


VPS-IMV
File Run View Window Options Help
View Merged Velocities
Location Sites Seismic Probes Merged Offsets Merged Cross-sections Merged elastic constants
Close

Depth	Segment length, metres	P-Velocity	S-Velocity	Soil density	Poisson ratio	Shear modulus	Lame constant	Young modulus	Bulk modulus
0.5	1.00111111111111	559.95	228.6	1800	0.4	94.06	376.26	263.38	438.97
1.5	0.89	238.34	97.3	1800	0.4	17.04	68.16	47.72	79.53
2.5	0.778888888888889	277.04	113.1	1800	0.4	23.02	92.1	64.47	107.45
3.5	0.667777777777778	293.45	119.8	1800	0.4	25.83	103.33	72.33	120.56
4.5	0.556666666666667	274.83	112.2	1800	0.4	22.66	90.64	63.45	105.75
5.5	0.445555555555556	256.71	104.8	1800	0.4	19.77	79.08	55.35	92.26
6.5	0.334444444444444	260.63	106.4	1800	0.4	20.38	81.51	57.06	95.1
7.5	0.223333333333333	295.9	120.8	1800	0.4	26.27	105.07	73.55	122.58
8.5	0.112222222222222	384.81	157.1	1800	0.4	44.42	177.7	124.39	207.32
9.5	0.00111111111111109	465.65	190.1	1800	0.4	65.05	260.19	182.14	303.56

Figure 13. *VSP-IMV®* user interface for viewing the merged databases.

2.3 Forward Modeling Downhill Simplex Method (FMDSM)

The FMDSM technique utilizes seismic ray tracing and optimal estimation techniques in deriving DST interval velocities. The standard techniques implemented in deriving DST interval velocities rely upon obtaining reference P and S wave arrival times as the probe is advanced into the soil profile or borehole. By assuming a straight ray travel path from source to seismic receiver and calculating relative reference arrival time differences, interval velocities are obtained.

The Forward Modeling / Downhill Simplex Method offers distinct advantages over conventional DST velocity profile estimation methods. Some of the advantages over conventional techniques provided by the FMDSM are outlined as follows

- Utilization of Snell's Law at layer boundaries for ray path refraction.
- Optimization of a cost function which takes into account more detail of the DST testing environment and subsequent seismic data recorded compared to standard techniques.
- Allowance for measurement weights to be specified, the possibility to incorporate unlimited input data (e.g., crossover point arrival times, maximum cross-correlation time shifts, angles of incidence, and P-wave / S-wave time separations) into the interval velocity estimation algorithm.
- The ability to accurately interpolate interval velocities when measurement data is not available.
- Provides meaningful error residuals which indicate the accuracy of the estimated interval velocity.

The FMDSM user interface window is enabled by either selecting sub-menu Run->Data Inversion or by selecting the icon from the toolbar illustrated in the main VSP-IMV® interface window. Figure 14 shows the main FMDSM user interface window.

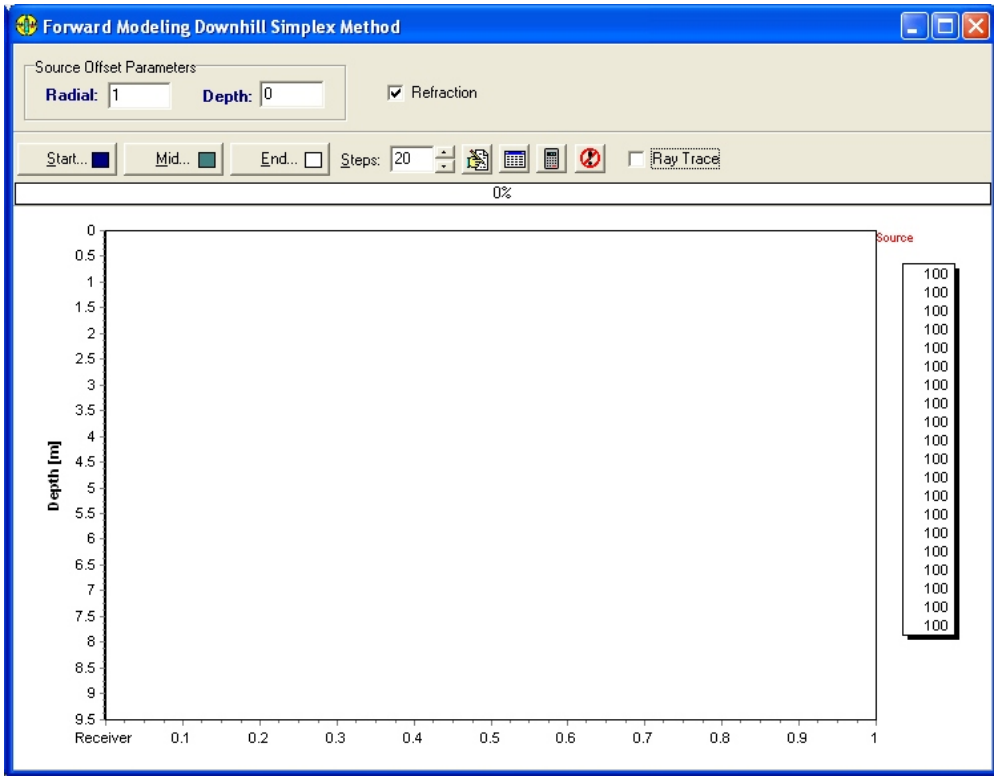


Figure 14. Main graphical interface screen in the *FMDSM* software option.

The first step in implementing the FMDSM is for the user to specify important parameters of source *Radial* Offset, source *Depth* offset and enable/disable raypath *Refraction*.

Radial: The radial offset of the DST source from the seismic receiver.

Depth: The depth offset of the DST source from the ground surface.

Refraction: The user enables raypath refraction at the previously defined stratigraphic layers by checking this box. If this box is left unchecked, straight raypaths will be assumed in the interval velocity estimation algorithm (reducing the required CPU).

Once the source offset and raypath type parameters have been specified, the user must setup or select a database which contains the required P-wave or S-wave arrival times. This step is carried out selecting the database icon . Upon selection of this icon the FMDSM graphical database interface illustrated in Figure 15 appears. The Seismic Probe is specified by selecting the appropriate *Country*, *Province/State*, *Site* and selecting the desired *Seismic Probe*. From the FMDSM database interface window the user then selects the appropriate *Offset*, *Velocity inversion profile* and *P-wave profile* or *S-wave profile*. For example, Figure 16 illustrates the site Site Rome->Probe #1 -> Rome Offset 1 -> Rome CS 1 -> S-wave profile user interface tab.

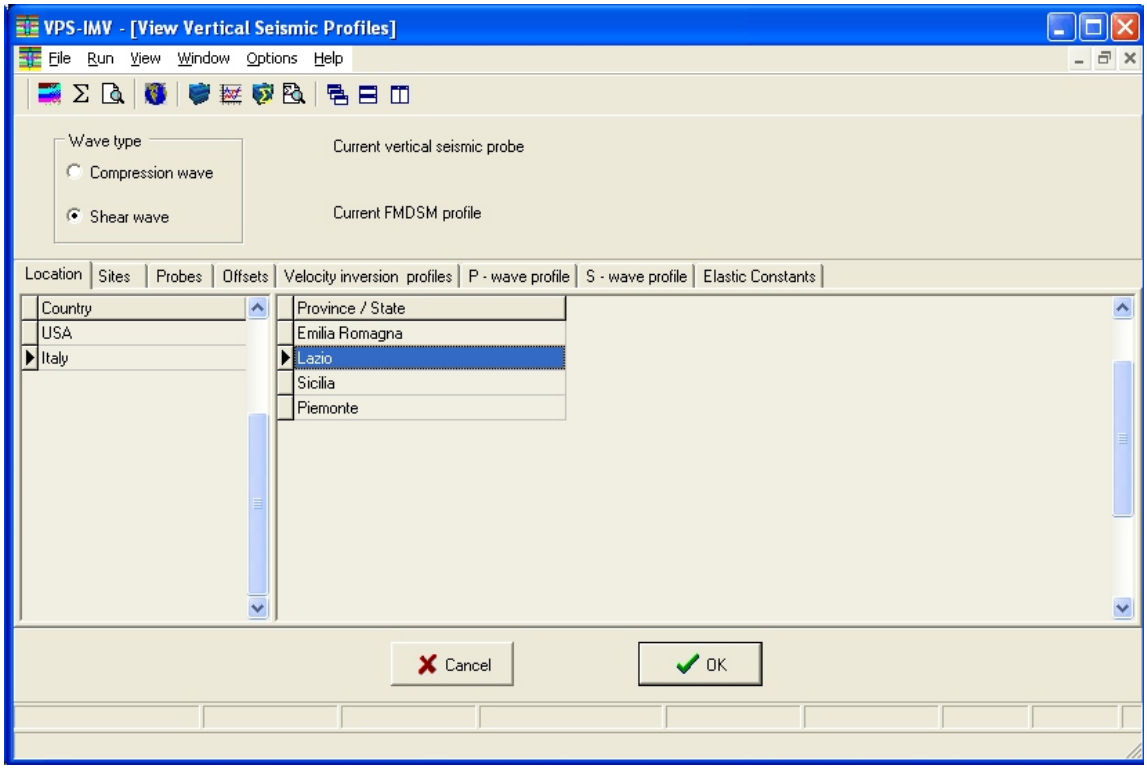


Figure 15. FMDSM main database interface window.

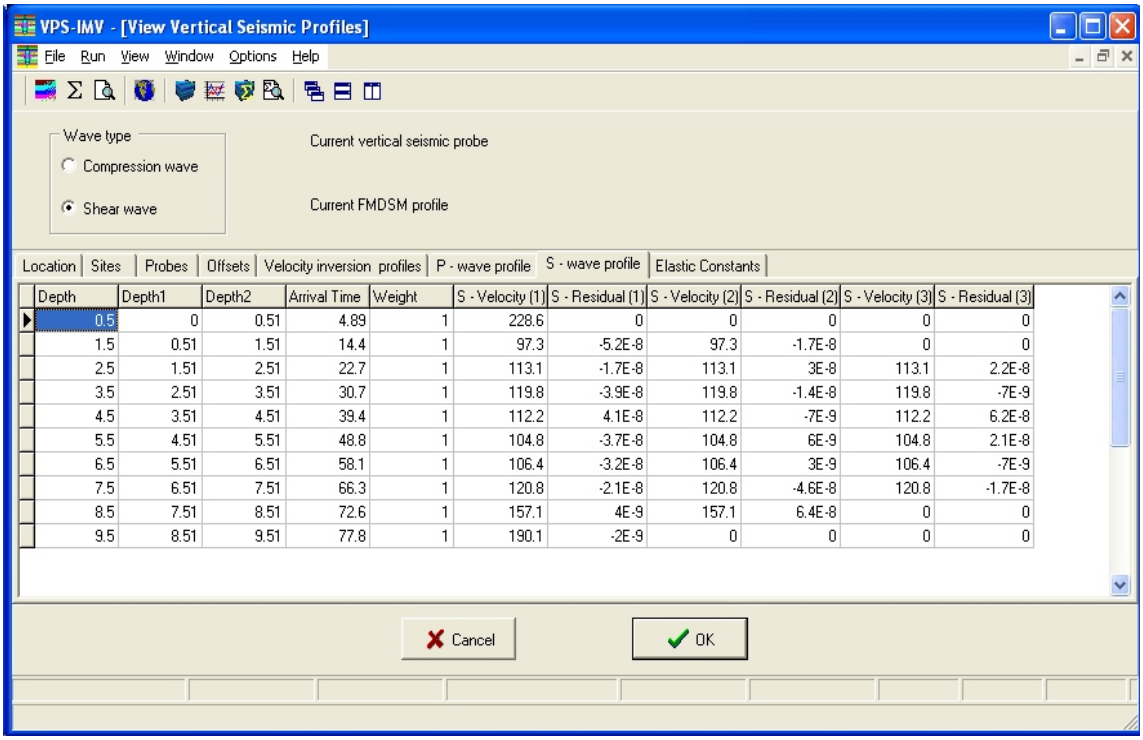

VPS-IMV - [View Vertical Seismic Profiles]
File Run View Window Options Help
Wave type
Compression wave
Shear wave
Current vertical seismic probe
Current FMDSM profile
Location Sites Probes Offsets Velocity inversion profiles P - wave profile S - wave profile Elastic Constants
Depth Depth1 Depth2 Arrival Time Weight S - Velocity (1) S - Residual (1) S - Velocity (2) S - Residual (2) S - Velocity (3) S - Residual (3)
0.5 0 0.51 4.89 1 228.6 0 0 0 0 0
1.5 0.51 1.51 14.4 1 97.3 -5.2E-8 97.3 -1.7E-8 0 0
2.5 1.51 2.51 22.7 1 113.1 -1.7E-8 113.1 3E-8 113.1 2.2E-8
3.5 2.51 3.51 30.7 1 119.8 -3.9E-8 119.8 -1.4E-8 119.8 -7E-9
4.5 3.51 4.51 39.4 1 112.2 4.1E-8 112.2 -7E-9 112.2 6.2E-8
5.5 4.51 5.51 48.8 1 104.8 -3.7E-8 104.8 6E-9 104.8 2.1E-8
6.5 5.51 6.51 58.1 1 106.4 -3.2E-8 106.4 3E-9 106.4 -7E-9
7.5 6.51 7.51 66.3 1 120.8 -2.1E-8 120.8 -4.6E-8 120.8 -1.7E-8
8.5 7.51 8.51 72.6 1 157.1 4E-9 157.1 6.4E-8 0 0
9.5 8.51 9.51 77.8 1 190.1 -2E-9 0 0 0 0
Cancel
OK

Figure 16. Automatic insertion of the estimated interval velocities and corresponding error residuals into the *S-wave profile* database.

In the S-wave profile database interface tab shown in Figure 16 the user must specify the appropriate seismic probe depth (Depth (m)) and the corresponding S-wave arrival time (ms) with the associated measurement weight (0-1). The user must also select the appropriate Wave type (Compression or Shear) which is to be analysed. It is required to input at least one arrival time with the corresponding weight for each depth increment (i.e., we need a least one piece of data for each depth increment to obtain an interval velocity estimate). The parameters Depth1 and Depth 2 identify the stratigraphic layering for the interval velocities to be estimated. These parameters are automatically set based upon the previously specified seismic probe depths (Depth).

If the user requires to derive unknown V_p or V_s interval velocities via Poisson's Ratio and the Elastic Constants database, then these values must firstly be set to zero within the appropriate P-wave or S-wave velocity profile window. The interval velocities to be calculated via Poisson's ratio can be initialized to zero by selecting push buttons *Clear P-wave data* or *Clear S-wave data* in the *Velocity inversion profiles* user interface tab as was illustrated in Figure 9.

Once the user has populated the database under study with the appropriate time and weight information he/she selects push button OK shown in Figures 15 and 16.The user then selects icon within the main FMDSM user interface window in order to implement the FMDSM algorithm and have corresponding interval velocities estimated. The user may abort the FMDSM by selecting icon . Upon completion of the FMDSM, a graphical screen similar to that illustrated in Figure 17 appears. Figure 17 illustrates a graphical representation of the estimated interval velocities with ray tracing implemented by checking box Ray Trace. The colour gradient of the graphic can be changed by selecting push buttons Start..., Mid..., and End... Dial Steps allows the user to modify the colour step increments in the interval velocity display. The estimated interval velocities are automatically entered into the previously selected P-wave profile or S-wave profile database as shown in Figure 16.

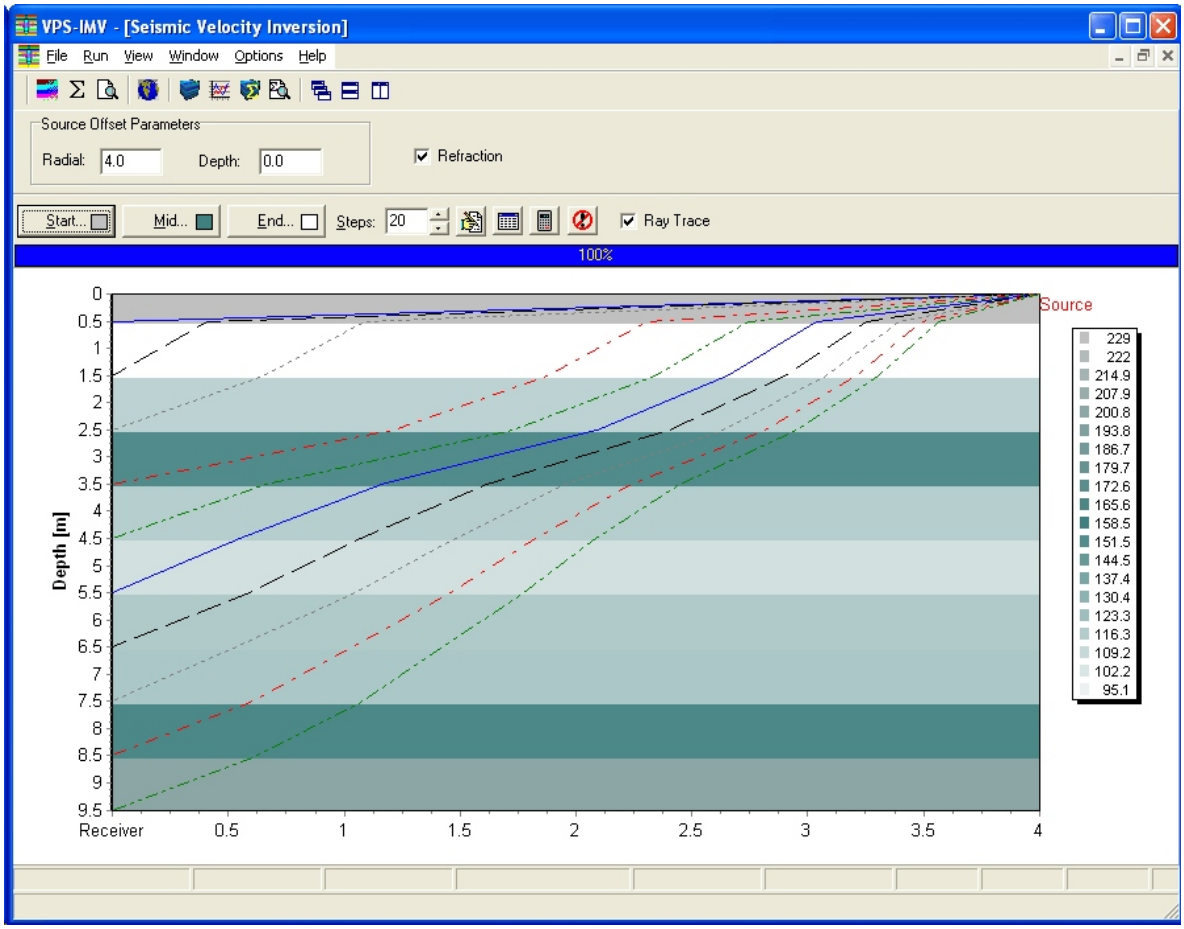


Figure 17. *FMDSM* graphical screen after completion of the interval velocity profile estimation.

The FMDSM is capable of estimating up to three interval velocities. These value are represented by columns S-Velocity (1) (m/s), S-Velocity (2) (m/s) and S-Velocity (3) (m/s). Due to the structure of the FMDSM, there is only one interval velocity for the first and last layers, while two interval velocities are available for the second and second to last layers. Interval velocities defined as 0 imply that no estimate was available. The user should place high weight on an FMDSM interval velocity profile when the three velocity columns (V1 (m/s), V2 (m/s), and V3 (m/s)) at each depth increment are nearly identical when an estimate is available and there are correspondingly low error residuals (implies a stable solution space). Significant variability in V1 (m/s), V2 (m/s), and V3 (m/s) and/or high error residuals is mostly likely associated with improperly specified arrival times or it maybe indicative of significant lateral soil heterogeneity.

The columns S-Residual (1) (ms), S-Residual (2) (ms) and P-Residual (3) (ms) identify the error residual between the specified Arrival Times and those values synthesized (Forward Modeling) by implementing the estimated interval velocities. The residuals give an indication of how well our estimated interval velocity model fits the measured data. Estimated raypaths are obtained which abide by Snell's law at the interfaces for the case when interval velocities are estimated assuming straight ray travel paths. The corresponding error residuals quantify the associated error with assuming straight ray travel paths when significant raypath refractions are occurring.

The user may now derive unknown interval V_p values from the estimated interval V_s values and Poisson's ratio if desired. To accomplish this task requires a two step process. Step 1 is to initialized the P-wave velocity profile to zero by selecting *Clear P-wave data* in the *Velocity inversion profiles* user interface tab as was previously outlined. Step 2 is to navigate to the Elastic Constants database user interface tab (as was shown in Figure 10) and input the known Poisson's ratio values.

2.4 Two Dimensional Interval Velocity and Elastic Constant Plotting

The output results of the FMDSM databases can be plotted by selecting sub-menu View->2D Viewer or by selecting the icon from the toolbar illustrated in the main VSP-IMV® interface window. Figure 18 illustrates the user interface for the 2D Viewer menu option. The steps in obtaining a 2D plot of a desired interval velocity or elastic constant are outlined as follows:

- Select appropriate country (Countries), province or state (Province/State) and Site Name.
- Select the desired Probes name from the Probes column.
- Select the desired Offset from the Offset column.
- Select the desired FMDSM cross-section from the Cross-section column.
- Select the desired parameter to display from the Parameter list box.
- Select the desired Plot Type. The user can either display the interval velocities in an Incremental Depth fashion as illustrated in Figure 19 or with Depth Bars as illustrated in Figure 20. The Incremental Depth graph plots the velocity estimate at the average depth of the two seismic traces used in the velocity calculation. Straight lines joining all the depth increments are then displayed. The Depth Bars plot illustrates the two depths from which the seismic traces in the velocity calculation were obtained by bars.

Once the above parameters have been specified the user then selects the Begin Processing push button.

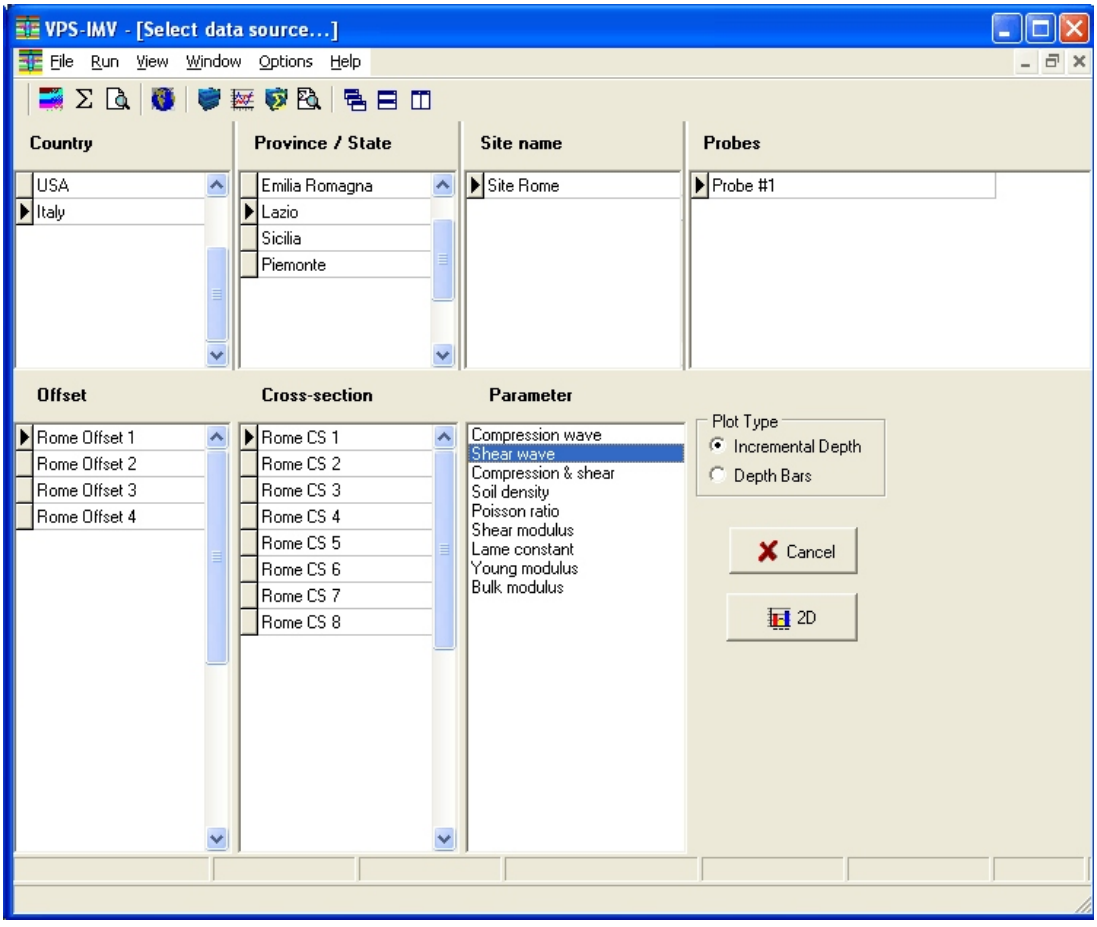


Figure 18. *2D Viewer* user interface.

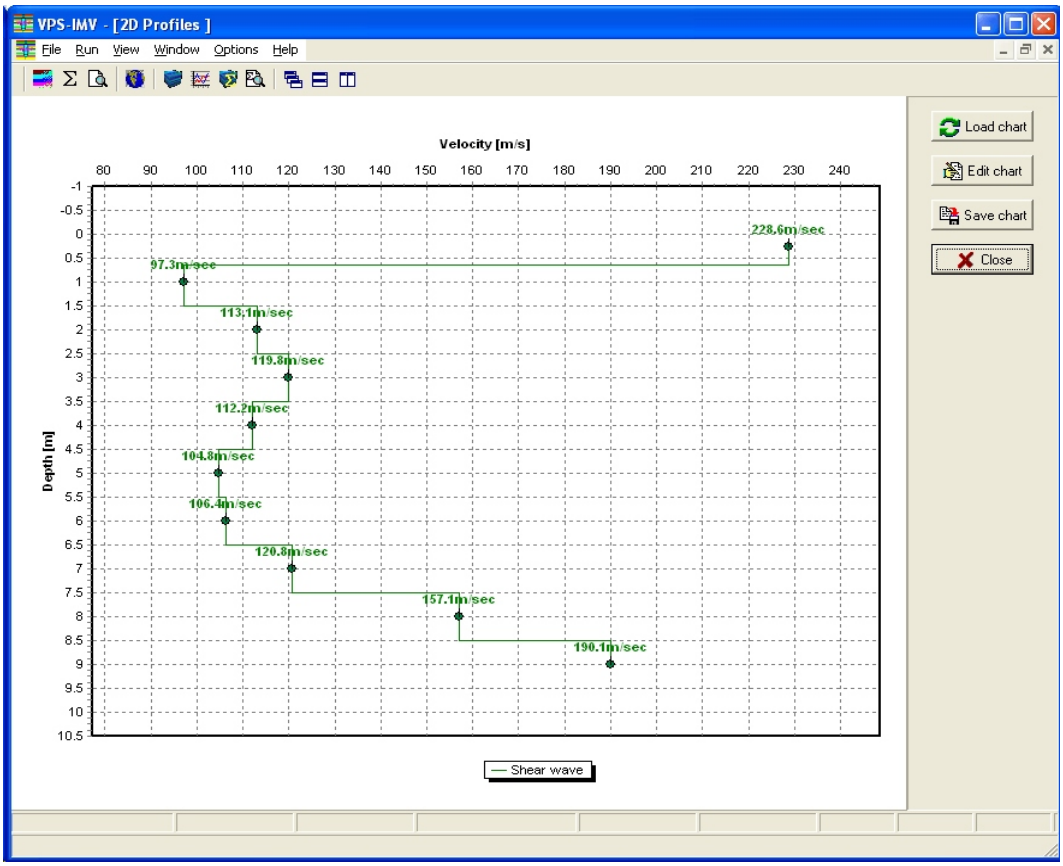


Figure 19. Plot of V_S interval velocities utilizing option *Incremental Depth* within *2D Viewer*.

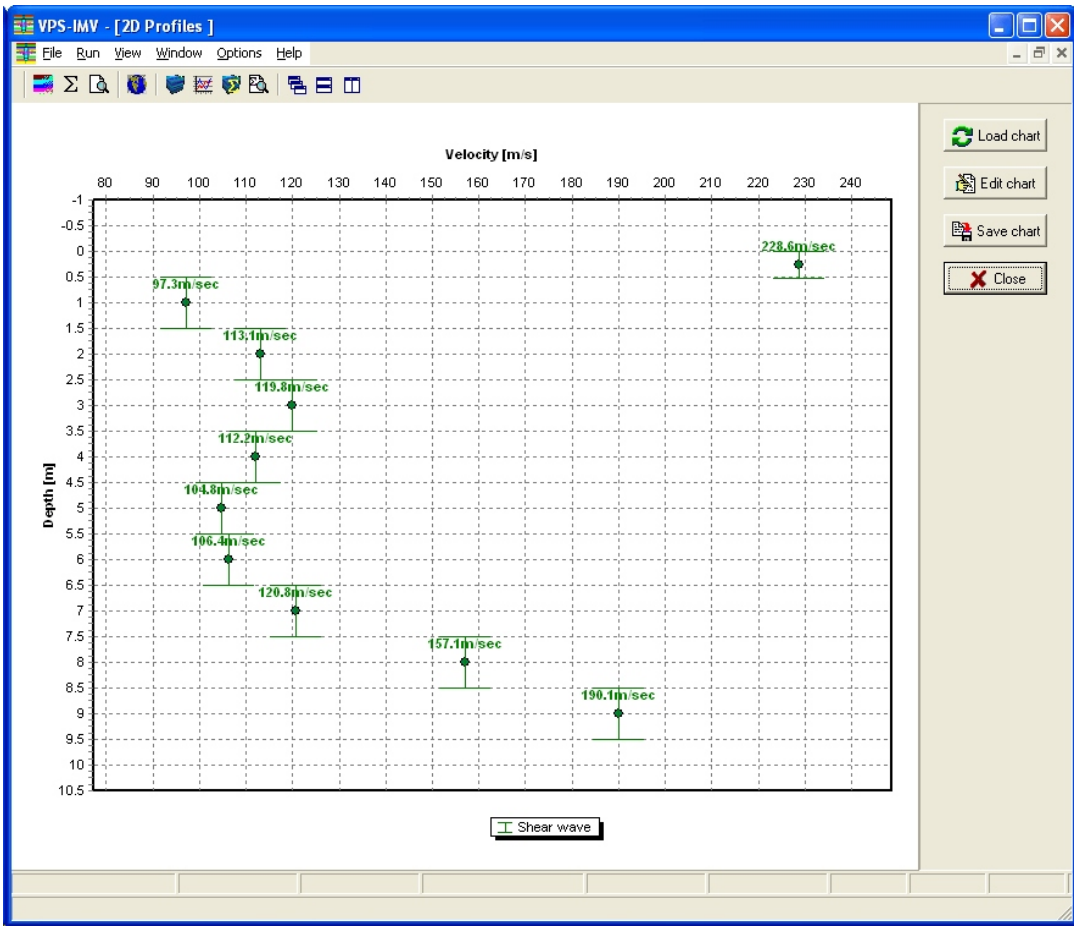


Figure 20. Plot of V_S interval velocities utilizing option *Depth Bars* within *2D Viewer*.

The button displayed at the top right hand corner of the previously illustrated graphs allows for chart formatting, printing, and exporting. Figure 21 illustrates the graphical interface that appears when the edit button is selected. The edit chart dialogue box allows for extensive modification of the displayed data and chart attributes. Figure 22 shows the chart print tab where the user specifies printer and printing parameters. The help button is selected to obtain detailed information on available functionality.

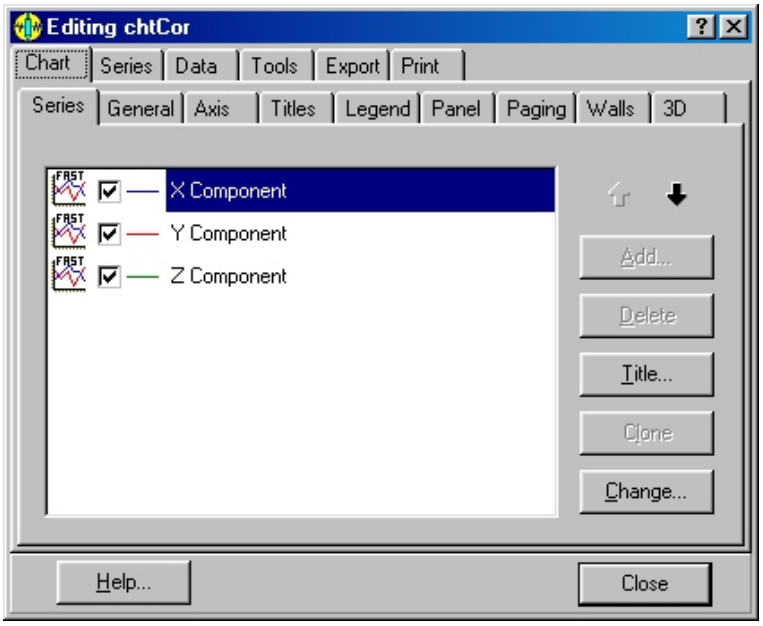


Figure 21. Chart editing dialogue box.

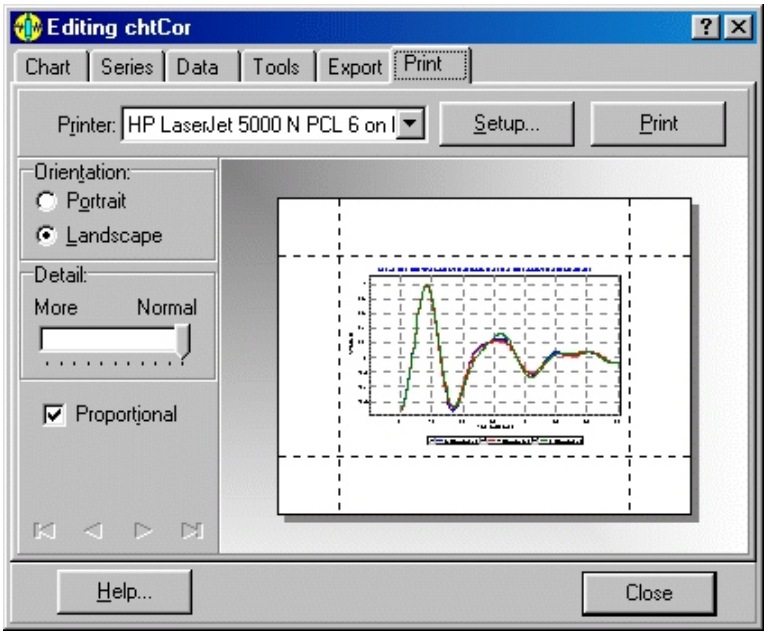


Figure 22. Chart printing dialogue box.

The user is also able to save the modified chart templates by selecting button . Once this button has been selected, a configuration file containing the template information is stored under subdirectory ..\MDI\chartCFG. Upon re-executing VSP-IMV®, the user may reload the chart template by selecting button Load chart .

2.5 Three Dimensional Tomographic Viewing

The VSP-IMV® software package provides highly advanced 3D viewing capabilities. The two types of 3D views provided are the standard 3D Viewer which allows for viewing of the FMDSM databases and the 3D Viewer (merged) which allows for viewing of the merged databases.

2.5.1 3D Viewer

The 3D viewer for the FMDSM databases is enabled by selecting sub-menu View->3D Viewer or by selecting the icon from the toolbar illustrated in the main *VSP-IMV®* interface window. Figure 23 illustrates the user interface for the 3D Viewer menu option. The steps in obtaining a 3D view of the desired interval velocity or elastic constant are outlined as follows:

- Select appropriate country (Countries), province or state (Province/State) and Site Name.
- Select the desired Probes name from the Probes column.
- Select the desired Parameter to be displayed from the Parameter column.
- Select the push button 3D.

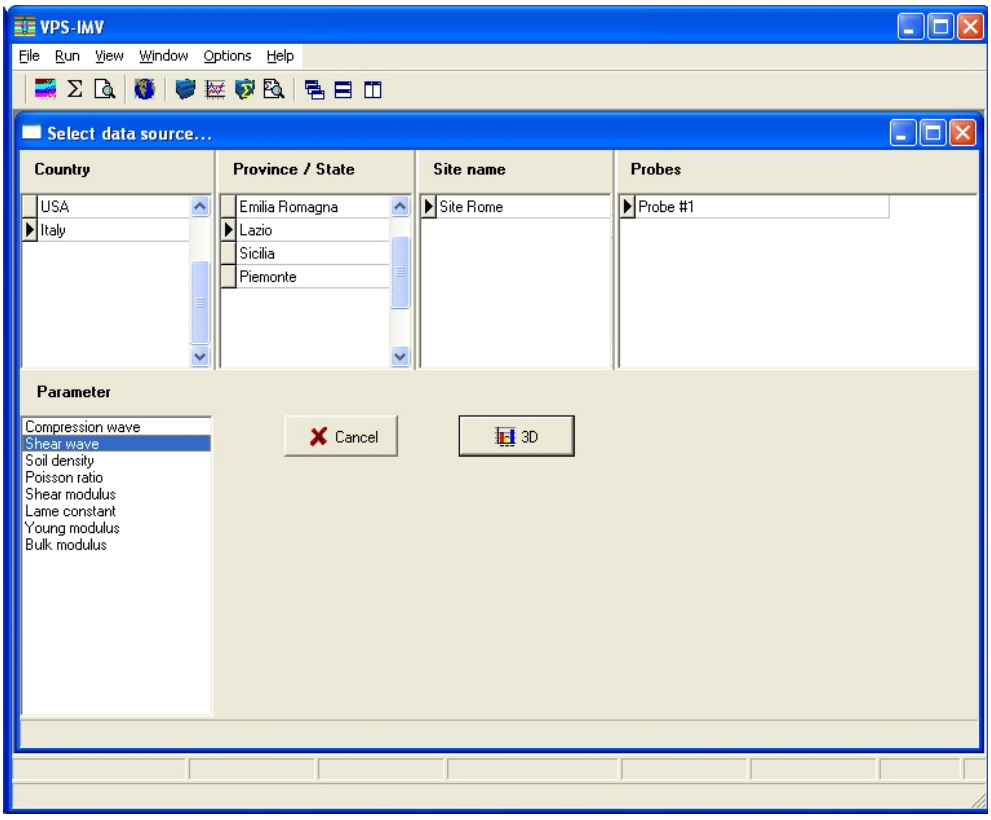


Figure 23. *3D Viewer* user interface.

Figure 24 illustrates a typical 3D graphical viewer for the FMDSM databases. In this case the shear modulus elastic constants are displayed. The tool bar at the bottom of the viewer shown in Figure 24 displays the Site latitude and longitude positional information and the Probe Name with it's corresponding latitude and longitude positional information. The user can move the centre position of the viewer by pressing down on the left hand mouse button and moving the image as desired. The image can be rotated by pressing down on the right hand mouse button and rotating the image as desired The viewing options made available to the user consist of Sidings, C-Sections, Dotted, Cone/Cube, Transparent, Animate, Light, Zoom Out, Zoom In, Colors, Copy, Z-axis, Blend, Position and Options. Many of these viewing options are self explanatory, but for completeness they are subsequently outlined as follows:

Sidings: when this option is enabled, the individual 2D FMDSM cross-sections are displayed. Since the FMDSM databases do not contain the merged tomographic results, this option in the standard 3D Viewer only overlays the results from all the FMDSM cross-sections for a particular Probe.

C-Sections: when enabled the FMDSM cross-sections are displayed.

Dotted: this option allows the user to alternate between a dotted and grid based frame of reference.

Cone/Cube: this option allows the user to alternate between a cone (more appropriate) and a cube based visualization of the estimated soil properties.

Transparent: this option allows for transparency in the 3D display.

Animate: this option allows for the automated rotation of the 3D view.

Light: enable/disable 3D view lighting effects.

Zoom Out: zoom out within the current viewing window.

Zoom In: zoom in within the current viewing window.

Colors: this option allows the user to specify the 3D graphing colors.

Copy: this option allows the user to save the current 3D image disk within a *.bmp format. The user can then open and print the saved file under menu option File->Open bitmap.

Z-axis: display/remove the Z-axis display.

Blend: this option is more appropriate for the merged databases. If the Blend option is enabled it is assumed that there are transitional changes from cell element to element as opposed to having distinct cell boundaries

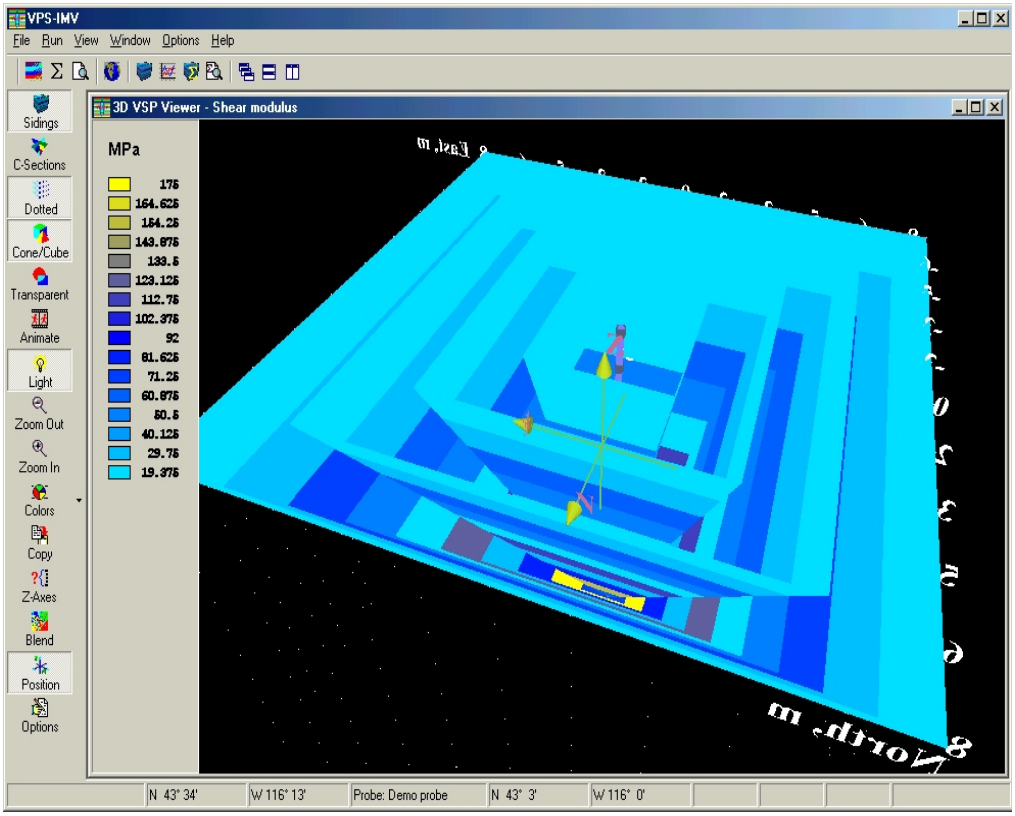


Figure 24. Typical 3D graphical view of FMDSM databases.

Position: display/remove 3D crosshair which shows Z, Easting, and Northing coordinate system.

Options: the Options user interface is illustrated in Figures 25(a), (b), and (c). The *Active offsets* user interface tab shown in Figure 25(a) allows the user to individually turn off the display of configured Offsets and their corresponding FMDSM profiles. This is advantageous in the sense that the in the standard 3D viewer the FMDSM profiles have not been merged and the user would most likely prefer to view a specified Offset with it's corresponding profiles.

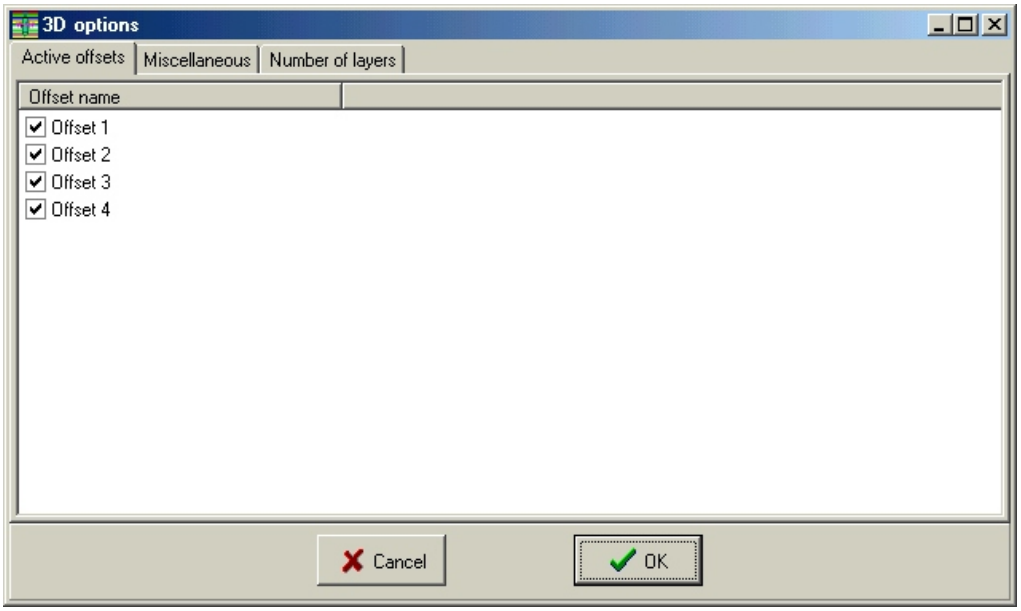


Figure 25(a). *Active offsets* user interface tab within the 3D Options for the standard viewer.

Figure 25(b) illustrates the *Miscellaneous* user interface tab. The *Miscellaneous* option allows the user to set the 3D graphical display fonts and the Animate rotation rate. Figure 25(c) illustrates the *Number of Layers* user interface tab. The *Number of Layers* option allows the user to specify the number of stratigraphic layers to display. For example, Figure 26 illustrated a standard 3D graphical display with Offsets 1 and 4 enabled Cube display set and *Number of Layers* set to 3.

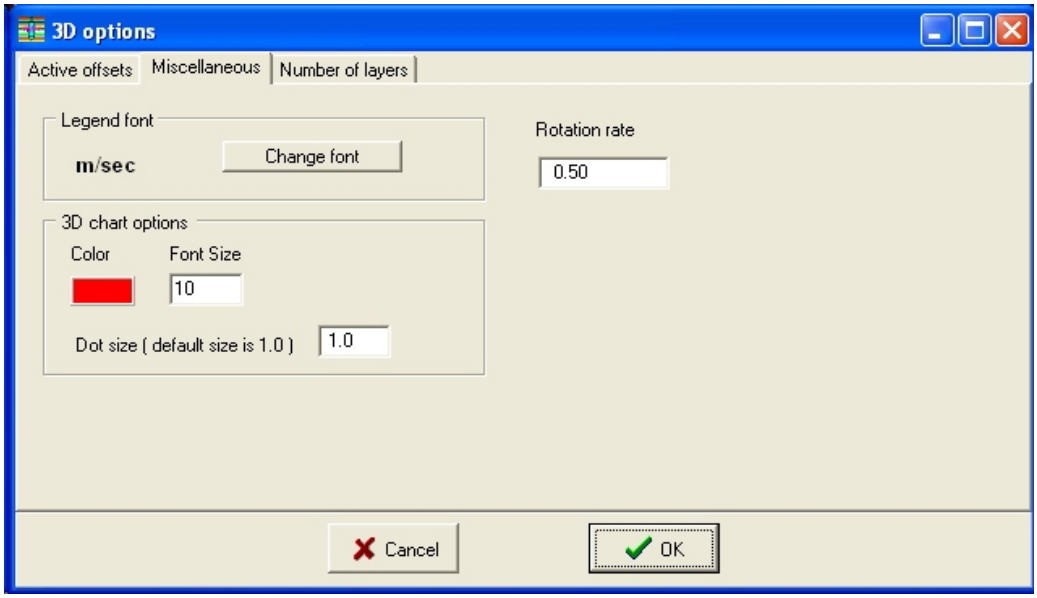


Figure 25(b). *Miscellaneous* user interface tab within the *3D Options* for the standard viewer.

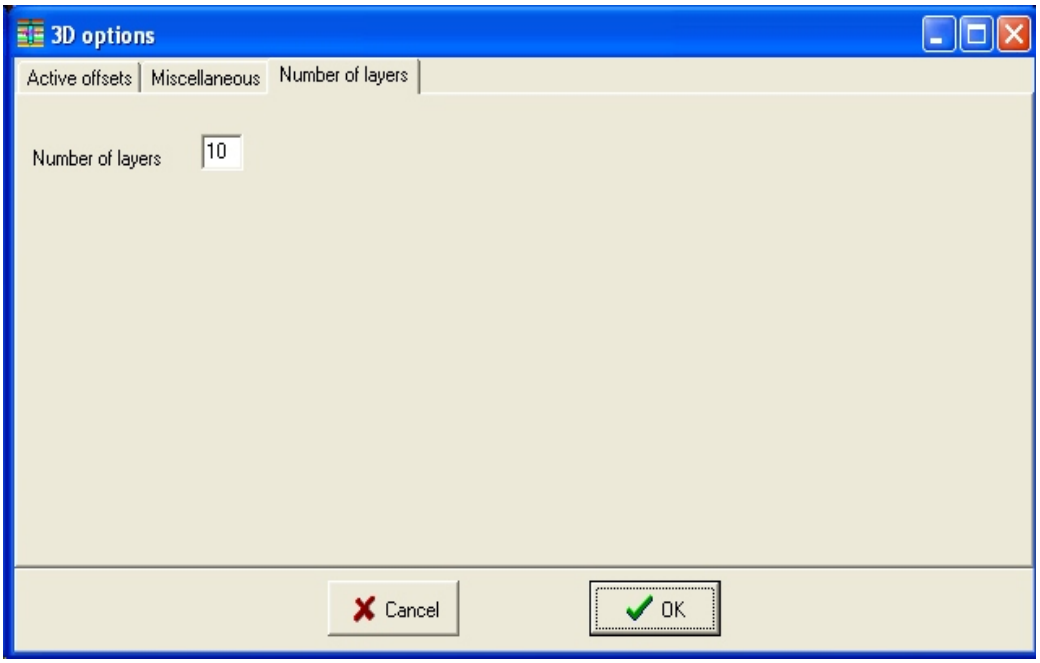


Figure 25(c). *Number of layers* user interface tab within the *3D Options* for the standard viewer.

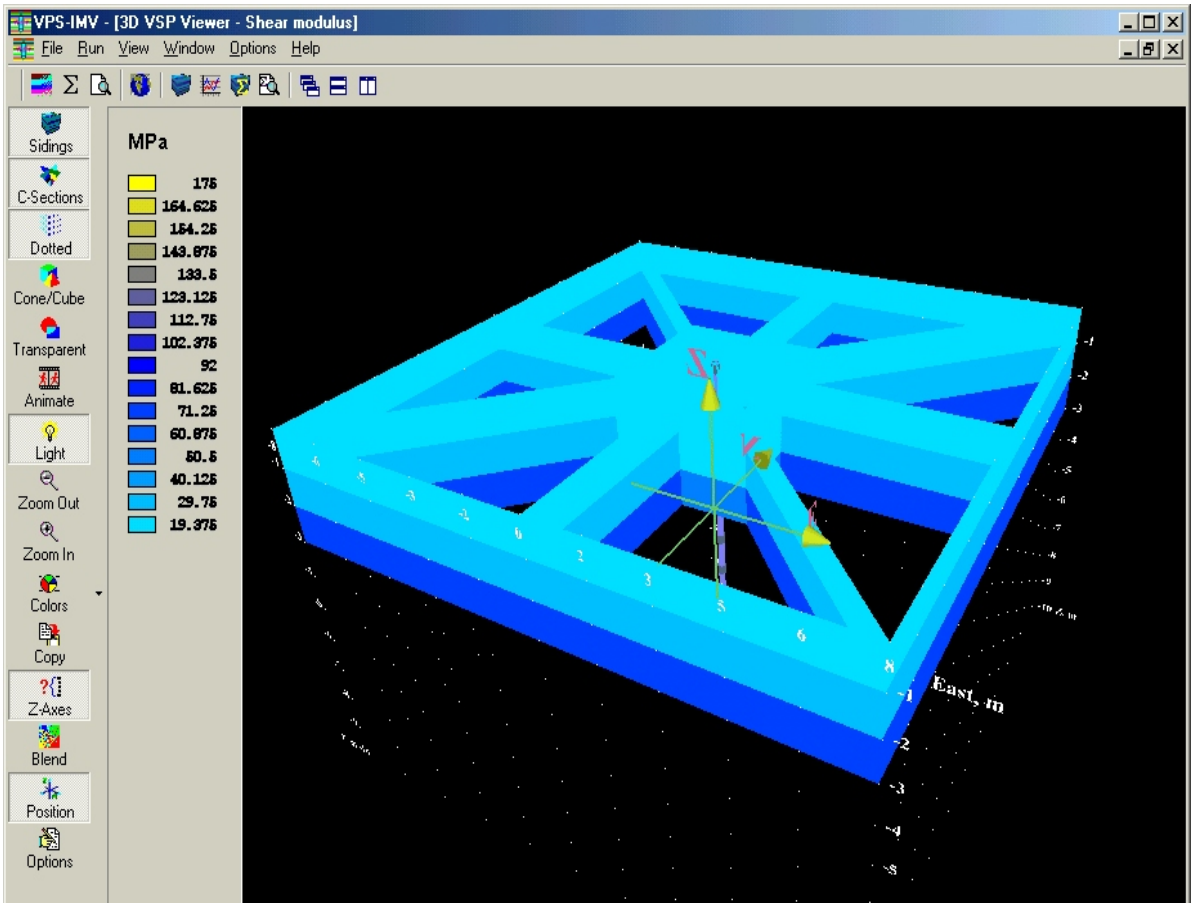


Figure 26. Illustration of a standard 3D graphical display with *Offsets 1* and *4* enabled, *Cube* display set and *Number of Layers* set to 3.

2.5.2 3D Viewer (merged)

The 3D viewer for the merged FMDSM databases is enabled by selecting sub-menu View->3D Viewer (merged) or by selecting the icon from the toolbar illustrated in the main *VSP-IMV®* interface window. The 3D Viewer (merged) menu option is nearly identical to the standard 3D viewer interface illustrated in Figure 23. The only difference is that the 3D Viewer (merged) user interface identifies whether an elastic parameter has been merged. The steps in obtaining a 3D view of the desired merged interval velocity or elastic constant are outlined as follows:

- Select appropriate country (Countries), province or state (Province/State) and Site Name.
- Select the desired Probes name from the Probes column.
- Select the desired Parameter to be displayed from the Parameter column.
- Select the push button View 3D.

Figure 27 illustrates a typical merged 3D graphical view where there are eight 2D tomographic images which have sensor-source offsets of 2 m, 4 m, 6 m and 8 m and go down to a depth of 10 m at 1 m increments. The combined bearing lines of the cross-sections provide for a 360° view around the seismic cone test hole where cross-sections are offset from one another by 45°.

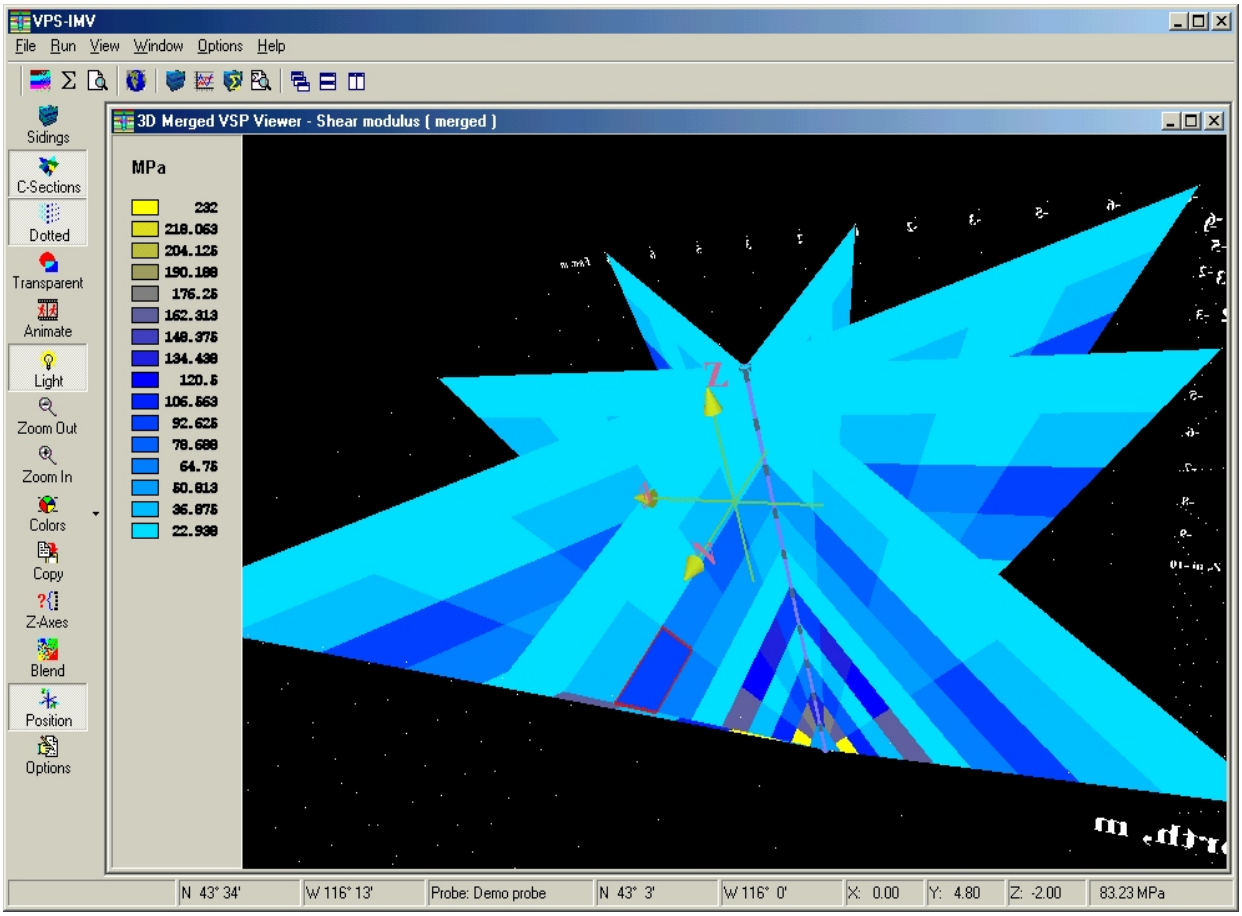


Figure 27. Typical graphical view of merged FMDSM databases.

The display in the 3D viewer is user interactive in the sense that the user can click on a specific area within the 3D view and obtain the location and magnitude of the interval parameter for the selected area. For example, in Figure 27 the area of interest is highlighted by a red rectangular box and the numerical position and interval value of the top left hand corner of the box is displayed in the tool bar at the bottom of the chart (ie., X: 0.00 m, Y: 4.80 m, Z: -2.00 m, and G_0 = 82.23 MPa).

Figure 28 shows a view of Figure 27 where it is assumed that there are transitional changes from cell element to element as opposed to having distinct cell boundaries (Blend option enabled). Figure 29 illustrates the superposition of interpolated cone surfaces which have a surface radius corresponding to the appropriate source offsets. As is evident from Figures 27, 28 and 29, the incorporation of the eight 2D tomographic cross-sections and the four interpolated cone surfaces provides for a 3D view of the in-situ SH velocities. The investigator could obtain a more detailed 3D tomographic image by implementing a denser configuration of source bearing lines.

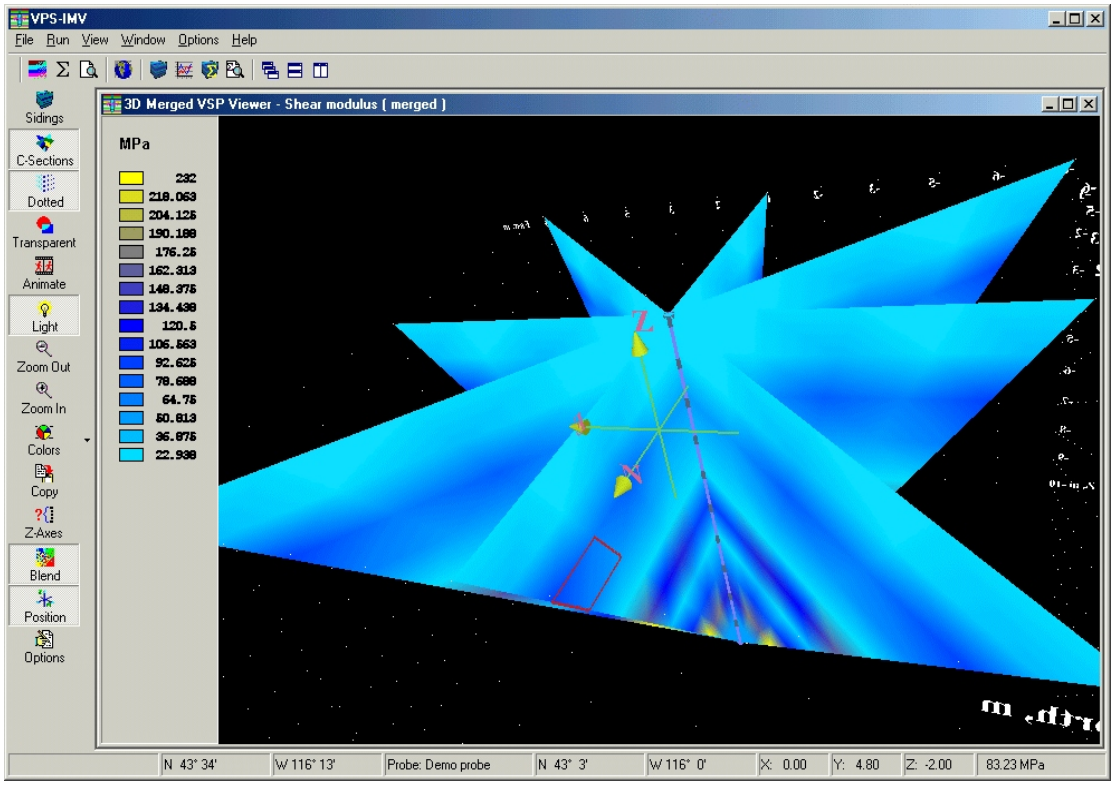


Figure 28. Typical graphical view of merged FMDSM database which demonstrates the *Blending* option.

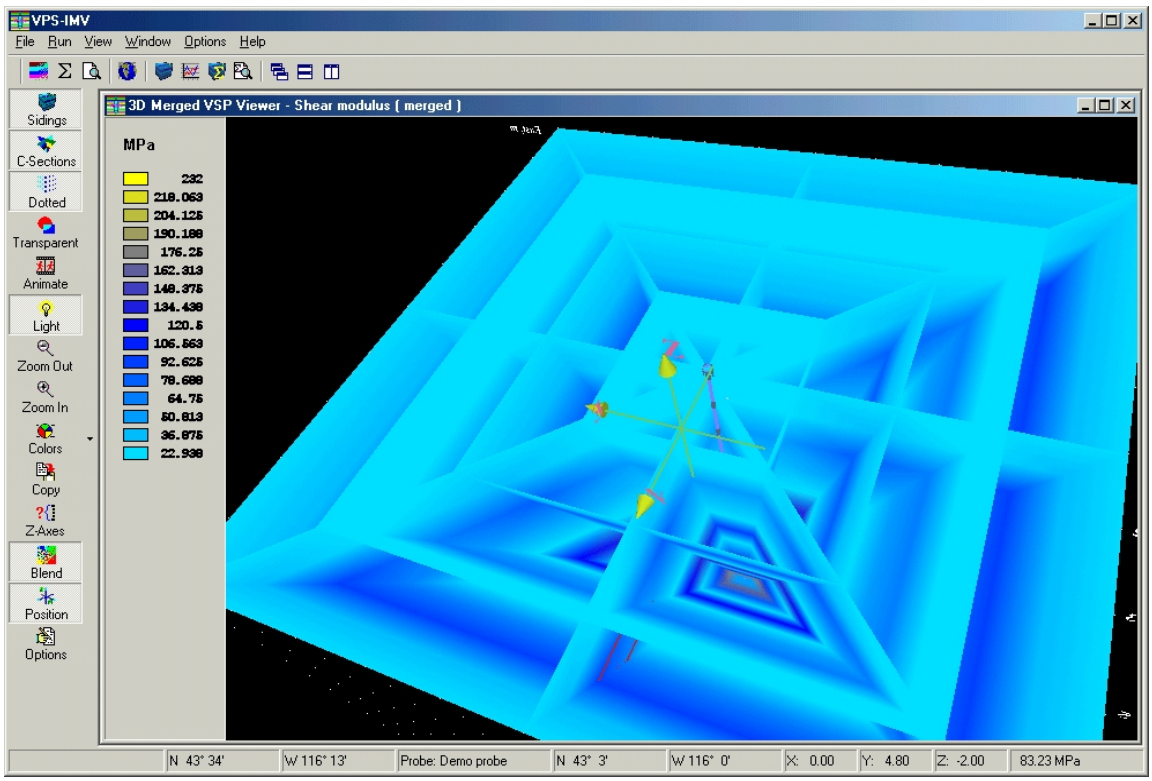


Figure 29. Superposition of 3D cone surfaces onto 2D tomographic cross-sections illustrated in Figure 31.

The viewing options for 3D merged viewer are nearly identical to those for the standard 3D viewer except for the additional functionality provided for in *Options*. In addition, the Cone/Cube option is not made available due to the nature of the FMDSM merging algorithm. Only cone cross-sections and surfaces are displayed in the 3D merged viewer.

The 3D viewer of the merged FMDSM cross-sections has the additional *Options* of 3D Filling, Areas between offsets and Active V2D. The options of 3D Filling and Areas between offsets allow the user to fill the areas between adjacent merged cross-sections and cone surface with appropriately attribute coloured spheres (i.e., reflecting displayed elastic constants' value). The 3D Filling user interface tab is shown in Figure 30(a). The Dot Size parameter identifies the size of the sphere in pixels and the Dot density parameter specifies the density of spheres within the filling volume.

The Areas between fills user interface tab is illustrated in Figure 30(b). This 3D option allows the user to specify which areas are to be filled within the 3D merged view. The column Cross-Section # identifies the 2D tomographic cross-section (e.g., there are eight 2D cross-sections illustrated in Figures 27, 28 and 29), the column Layer # identifies a specific layer within the stratigraphic profile (e.g., there are ten stratigraphic layers illustrated in Figures 27, 28 and 29), and the Column Offsets # identifies the fill area between the selected Offsets at the previously specified 2D tomographic cross-section and stratigraphic layer. For example, if the user desired to fill the area at the first stratigraphic layer at the first Cross-section between the first and second cross-sections then the Visible check box Cross-Section # 0, Layer # 0, Offsets # 0 to 1 should be set to enabled.

The Active V2D option allows the user to individually turn off the display of specific areas of the 2D tomographic cross-sections based upon the corresponding Offsets. Figure 30(c) illustrates the Active V2D user interface tab. The user enables and disables the display of areas within the 2D cross-sections by checking and un-checking entries under column Merged cross-sections index. For the examples illustrated in Figures 27, 28 and 29 there are four Offsets; therefore, there should be four entries under Merged cross-section index as is shown in Figure 30(c). Figure 31 illustrates a merged 3D view where viewing options C-sections, Transparent, Light and Merged cross-section index's #2 and #3 have been enabled. In additions, the area in these selected zones has been filled at stratigraphic layers 1 and 3.

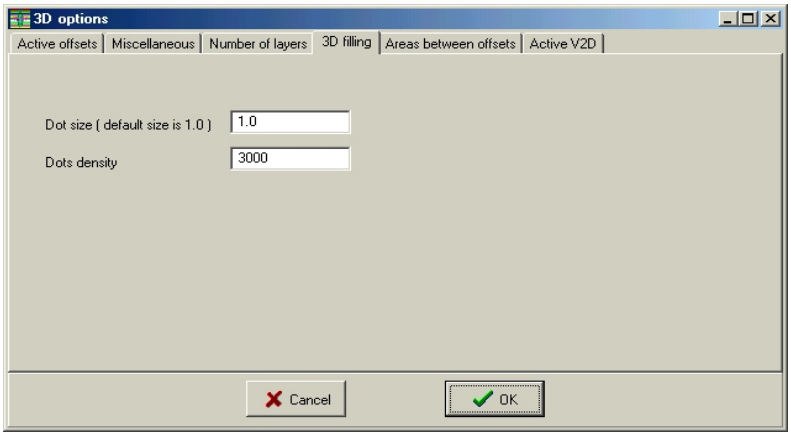


Figure 30(a). *3D filling* user interface tab.

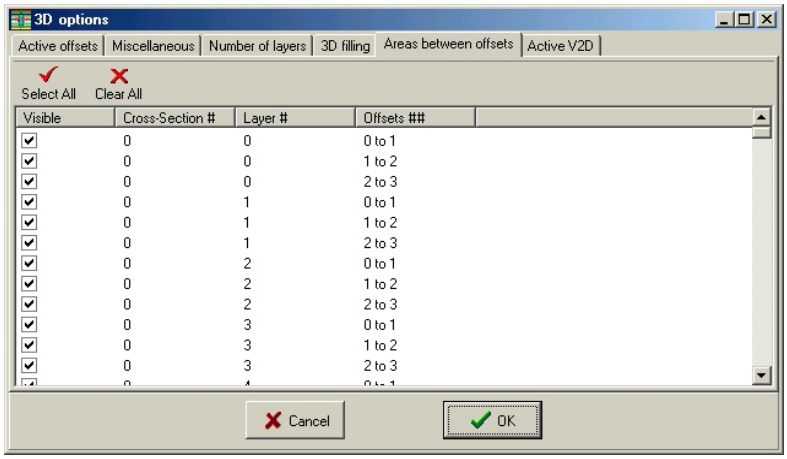


Figure 30(b). *Areas between offsets* user interface tab.

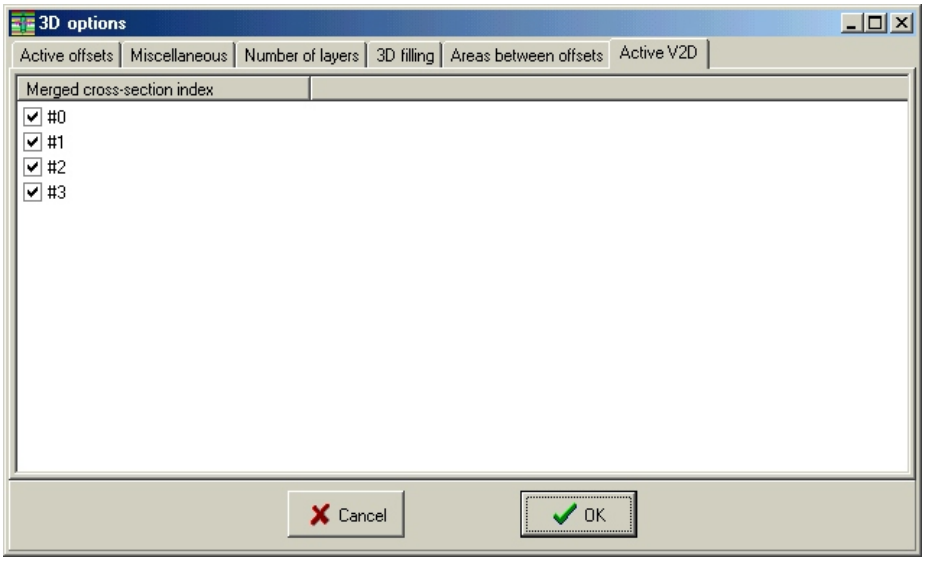


Figure 30(c). *Active V2D* user interface tab.

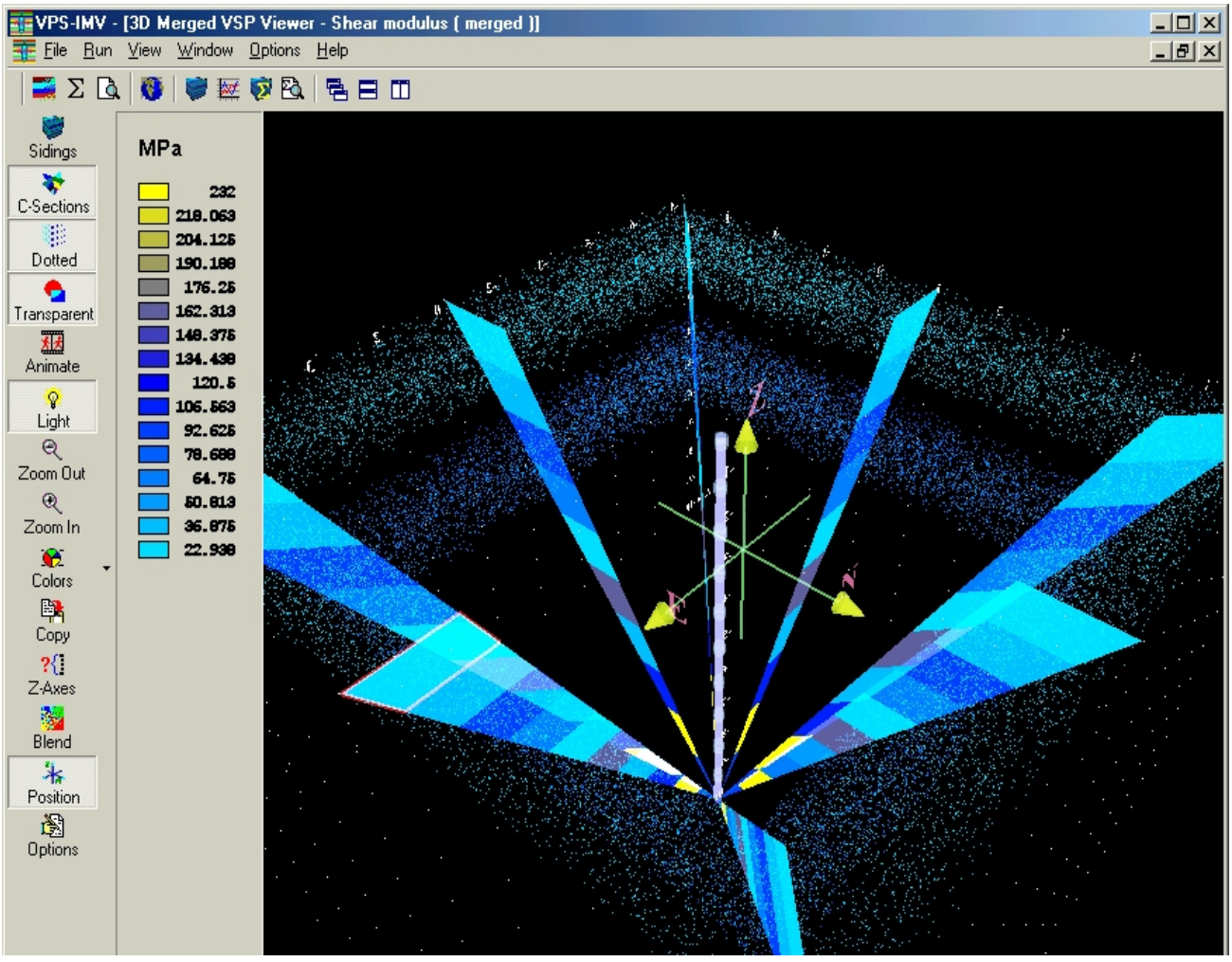


Figure 31. Merged 3D view where viewing options *C-sections*, *Transparent*, *Light* and *Merged cross-section index's #2* and *#3* have been enabled. In additions, the area in these selected zones has been filled at stratigraphic layers 1 and 3.

2.6 DST Geographic Information Systems

VSP-IMV® incorporates a geographic information system (GIS) with the ability to overlay results from the DST investigations from anywhere in the world. The GIS viewer is enabled by selecting sub-menu View->GIS map or by selecting the icon from the toolbar illustrated in the main VSP-IMV® interface window. When the GIS map option has been selected a digital map of the world is illustrated which contains icons which identify all the DST sites configured. Figure 32 shows the digital world map. In GIS maps provided all DST sites are identified as orange circular icons while the probe locations are identified as green circular icons. The current active site/probe is animated within the viewer. In addition, only the sites and probes related to the current map are displayed.

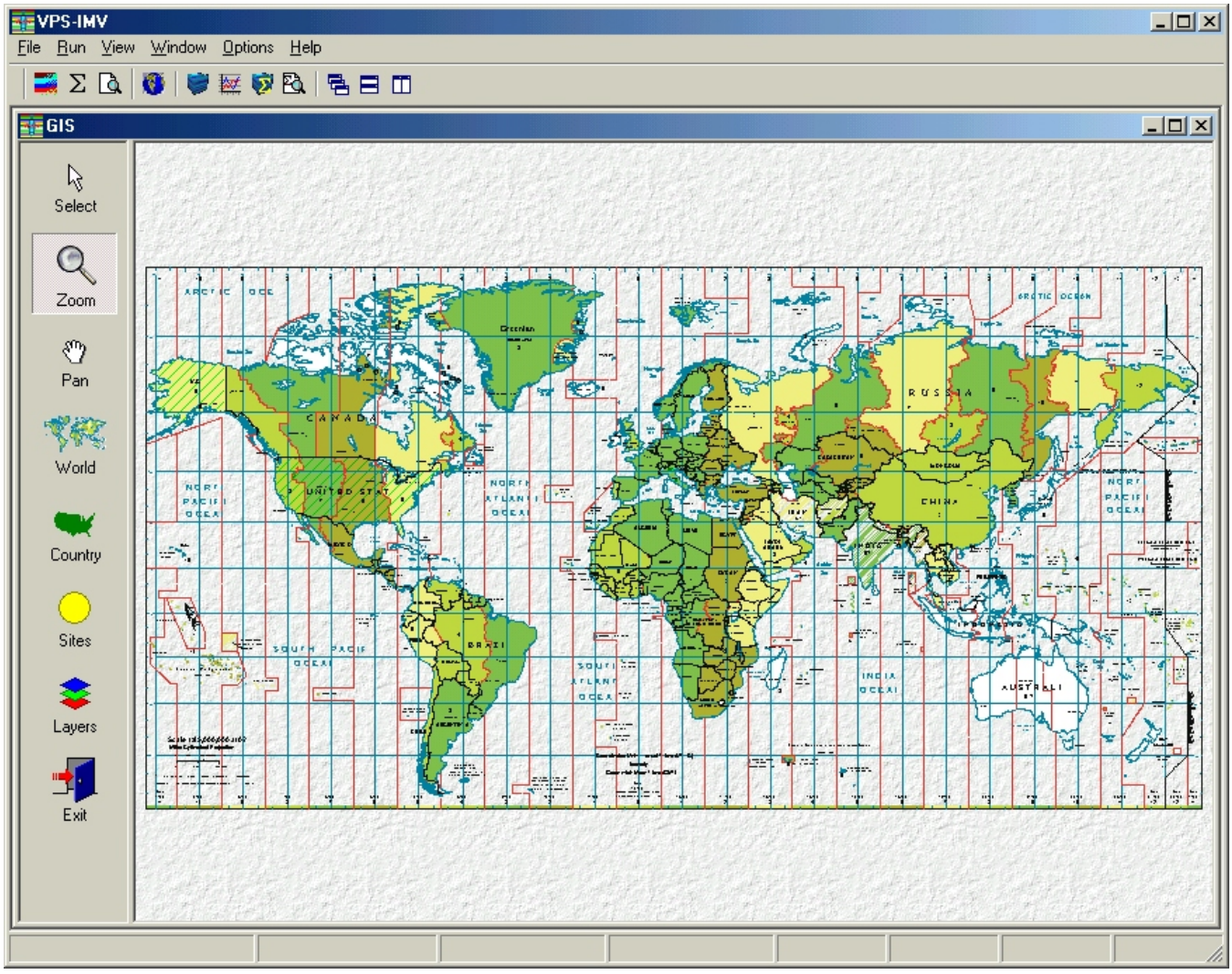


Figure 32. Digital world map displayed when GIS option selected.

The user can zoom into the map by selecting the Zoom menu option. Alternatively, the user can zoom out of the map by selecting menu option Zoom + the <ctrl> button. The Pan menu option allows for panning of the currently displayed map. The Sites menu option displays all the sites and probes and their corresponding positional information for the currently displayed map. Figure 33 illustrates the world map which has been zoomed in and panned to give a better presentation of Italy. In addition, the sites and probes are illustrated in the Sites dialogue box.

When enabled, the Layers menu option displays all available GIS attributes which can be turned on and off within the currently displayed map. For example, Figure 34 is illustrates the world map where the attributes of time Zones and map Grid have been turned off.

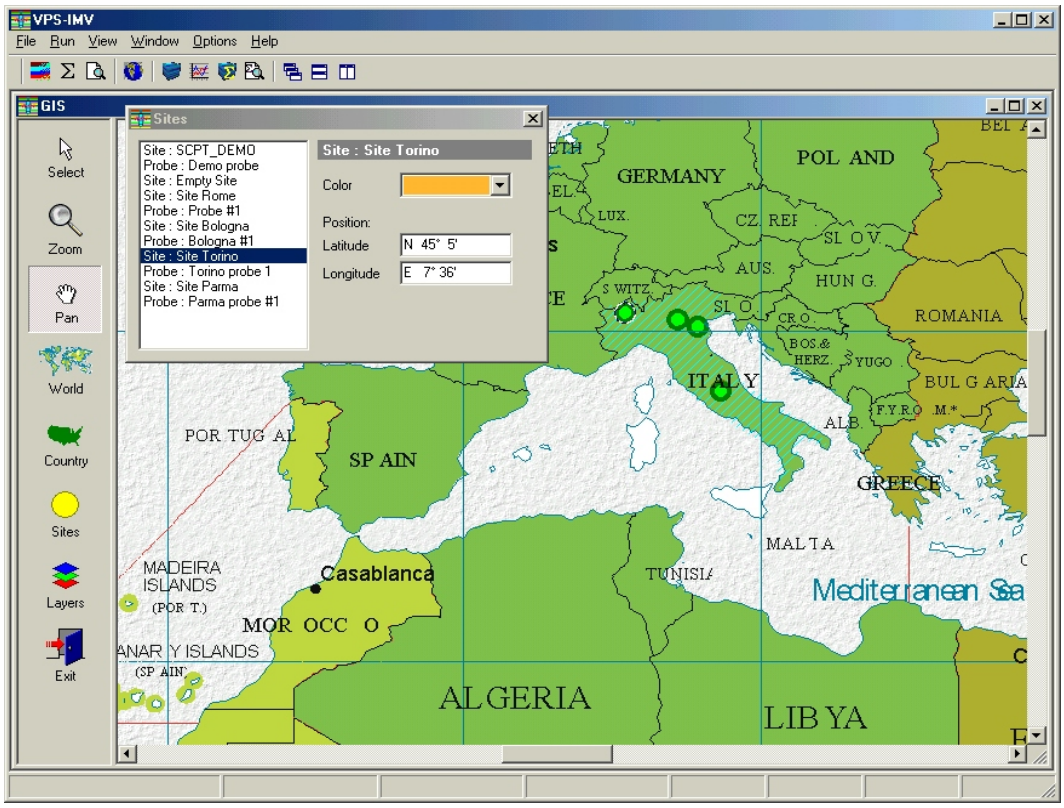


Figure 33. Illustration of the Sites dialogue box and the world map which has been zoomed in and panned to give a better presentation of Italy.

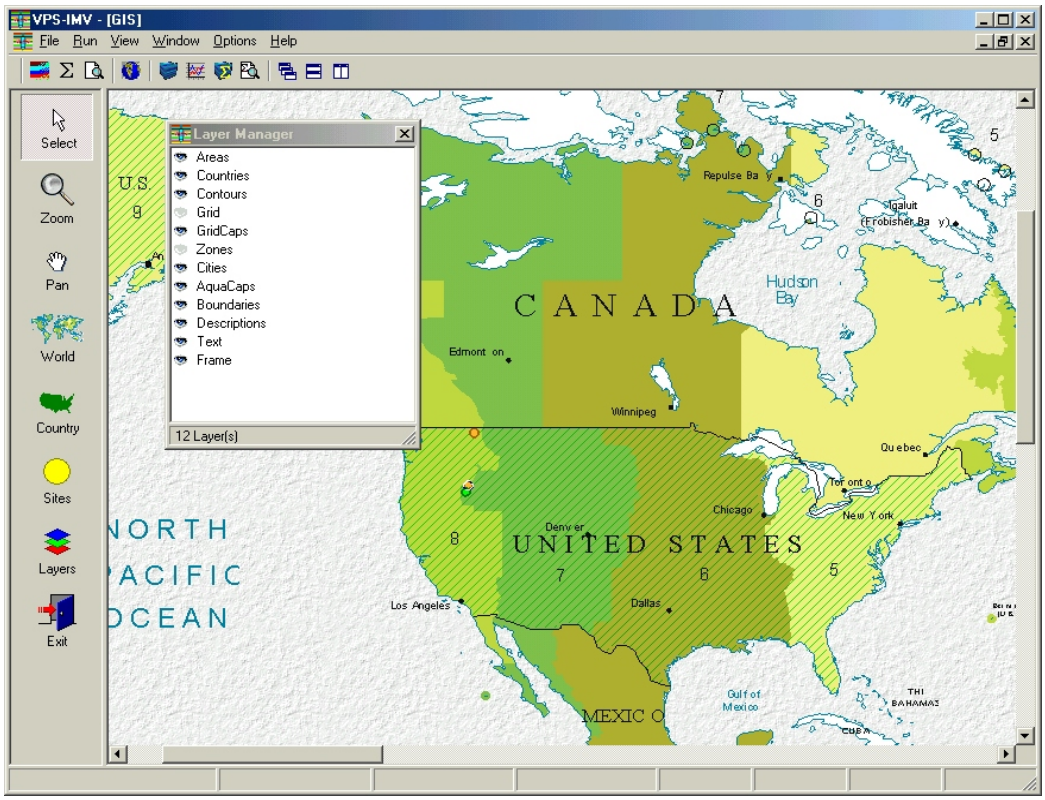


Figure 34. Illustration of Layers Manager where attributes of Grid and Zones (time) have been removed from the display in the world map.

The Select menu option allows the user to select more detailed maps of countries and associated provinces/states (single click of left mouse button) or select the database of the illustrated site and/or probe (double clicking of left mouse button). For example, Figure 35 illustrates a zoomed in view of a digital map for the Italian province of Emilia Romagna. This map was obtained by firstly selecting the country of Italy from the world map and secondly selecting the province of Emilia Romagna from the Italian map.

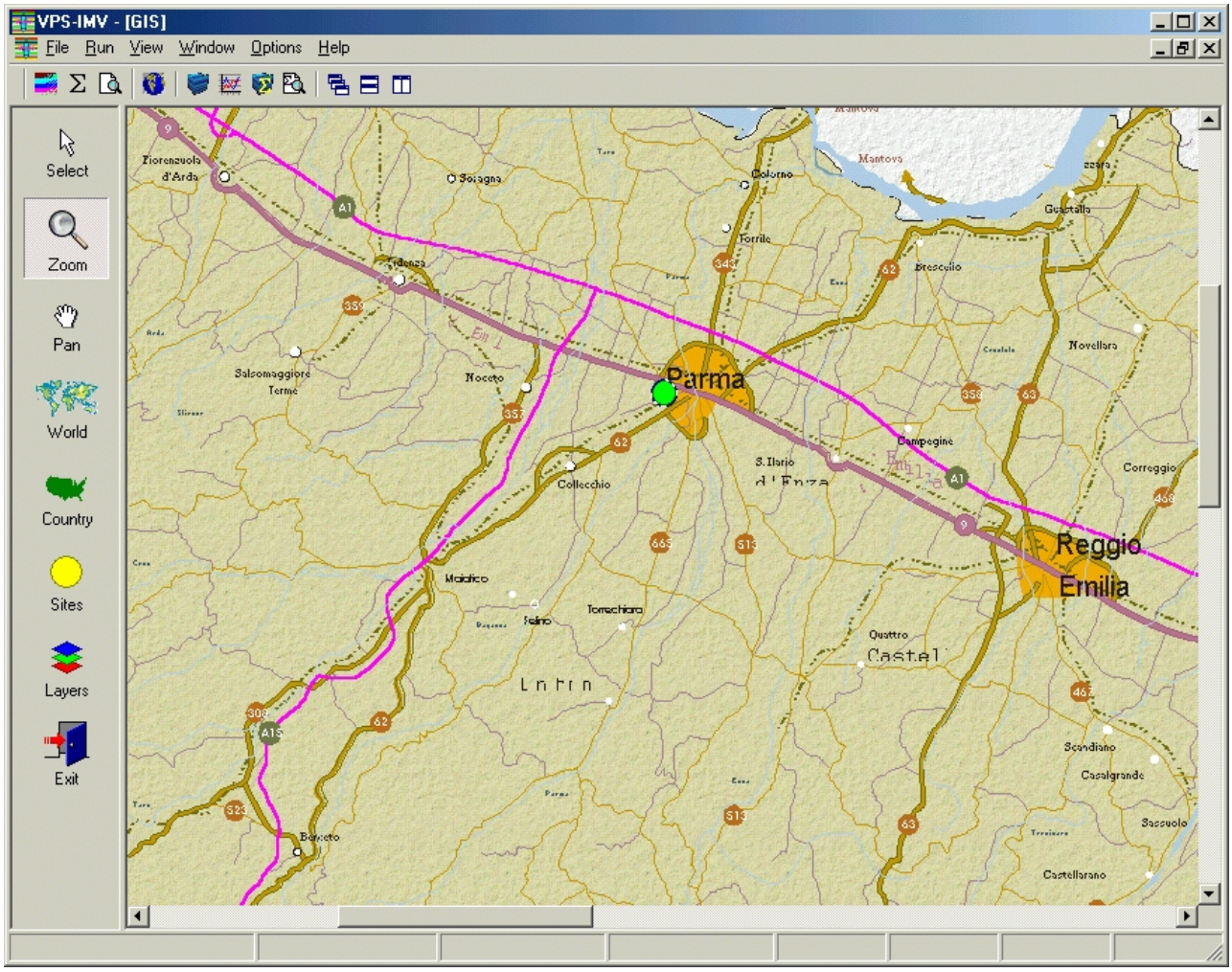


Figure 35. Zoomed in view of the Italian province of Emilia Romagna.

The selection of the World menu option will result in the re-display of the world map. The selection of the Country menu option will result in a pull down menu where all of the available countries which can be selected and displayed are outlined.

2.7 VSP-IMV® Options

VSP-IMV® allows the user to specify some basic 3D viewing and FMDSM configuration parameters.

2.7.1 3D Options

The 3D Options sub-menu allows the user to conFigure and save standard 3D viewing options to a configuration file. These configured parameters are automatically reloaded when the user re-executes *VSP-IMV®*. The 3D Options user interface is illustrated in Figure 36 where tabs Miscellaneous and 3D filling are shown. The 3D configuration parameters provided in these interface tabs are identical to those previously outlined in Section 2.5.

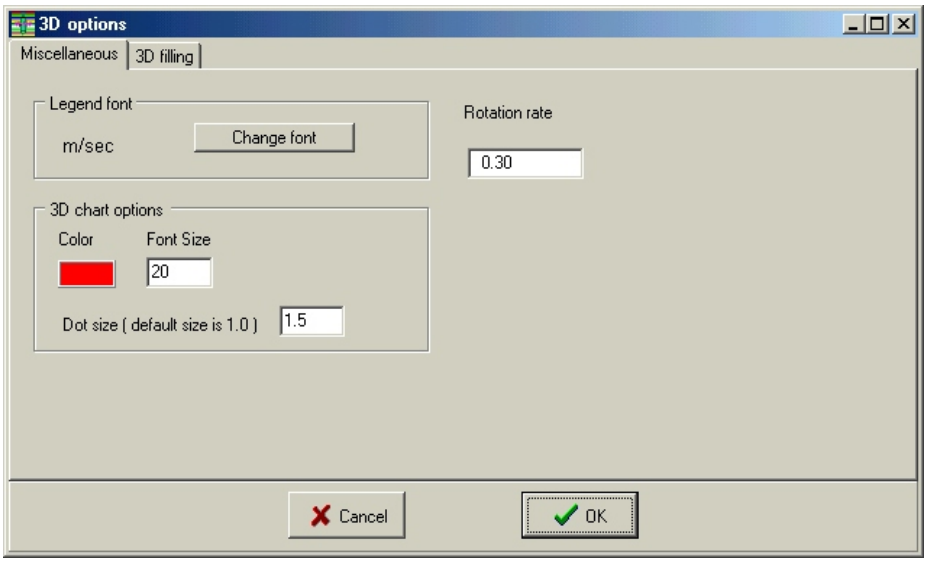


Figure 36. *3D Options* user interface.

2.7.2 FMDSM Options

The FMDSM options sub-menu allows the user to configure and save standard FMDSM viewing and analysis parameters to a configuration file. These configured parameters are automatically reloaded when the user re-executes *VSP-IMV®*. The FMDSM options user interface is illustrated in Figure 37 where tabs Strata Layering Specification, Cost Function Parameters and Source Offset Parameters are shown. The FMDSM configuration parameters provided in these interface tabs are identical to those previously outlined in Section 2.3.

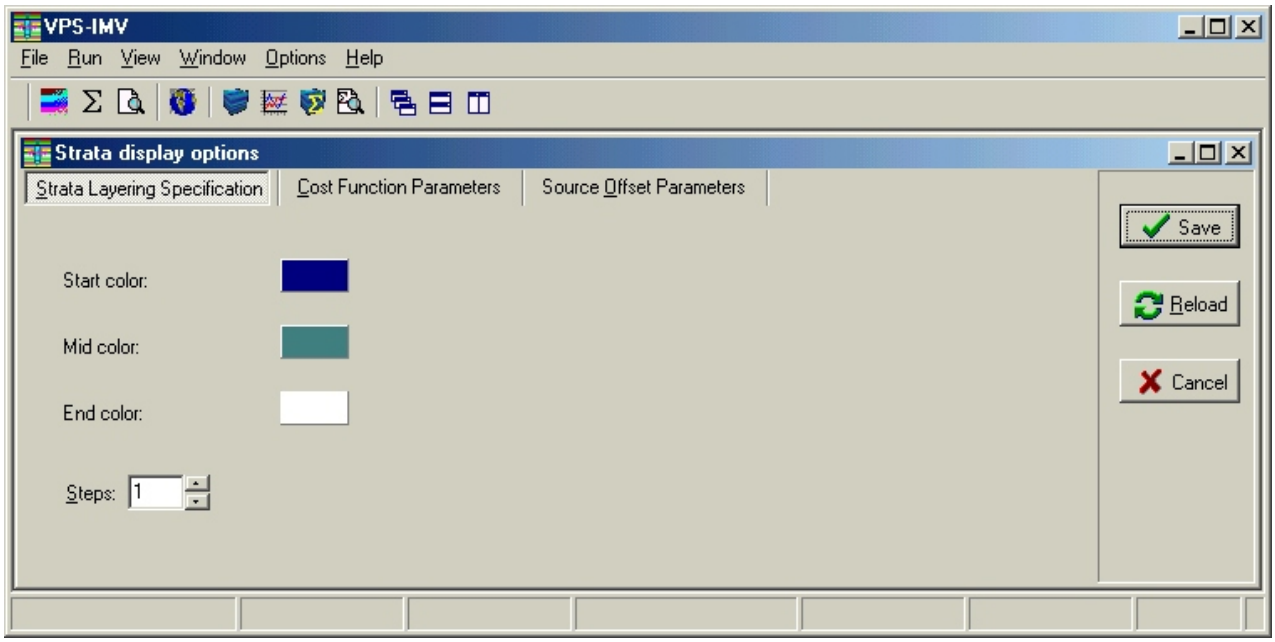


Figure 37. *FMDSM Options* user interface.

3.0 Help

The options associated with the Help Menu selection are as outlines as follows:

- About - provides software version information on VSP-IMV® .
- User's Manual - will output the VSP-IMV® user's manual in a PDF reader.
- Appendix 1 - will output the Appendix 1 paper in a PDF reader.
- Appendix 2 - will output the Appendix 2 paper in a PDF reader.
- Appendix 3 - Arrival times and probe depths for example database.
- Link to BCE - makes a link to Baziw Consulting Engineers' web page.

References

Andrus, R.D., Stokoe, K.H. and Chung, R.M. 1999. Draft guidelines for evaluating liquefaction resistance using shear wave velocity measurements and simplified procedures, NISTIR 6277.National Institute of Standards and Technology, Gaithersburg, Md.

Baziw, E.J. (2004), "Two and three dimensional imaging utilizing the seismic cone penetrometer ", presented at the International Conference on Site Characterization (ISC-2), September 20-22, 2004 in Porto, Portugal. Published in conference proceedings.

Baziw, E.J. (2002), "Derivation of Seismic Cone Interval Velocities Utilizing Forward Modeling and the Downhill Simplex Method", Can. Geotech. J. Vol. 39: 1-12.

Finn, W.D. Liam 1984. Dynamic response analysis of soils in engineering practice. Mechanics of Engineering Materials. John Wiley & Sons Ltd. Chapter 13.

Appendix 1: Baziw, E.J. (2002). Derivation of seismic cone interval velocities utilizing forward modeling and the downhill simplex method. Can. Geotech. J. Vol. 39: 1181-1192.

Appendix 2: Baziw, E.J. (2004). Two and three dimensional imaging utilizing the seismic cone penetrometer. Presented at the International Conference on Site Characterization (ISC-2), September 20-22, 2004 in Porto, Portugal. Published in conference proceedings.

Appendix 3: Arrival times and probe depths specified for the example database provided with the installation software. The same example database is utilized for Sites Idaho, Torino, Parma, Bologna and Roma.

XOffset = 1.0m			XOffset = 2.0 m			XOffset = 3.0 m			XOffset = 4.0 m		
Depth (m)	**Interval Velocity (m/s)**	**Arrival Time (ms)**	**Depth (m)**	**Interval Velocity (m/s)**	**Arrival Time (ms)**	**Depth (m)**	**Interval Velocity (m/s)**	**Arrival Time (ms)**	**Depth (m)**	**Interval Velocity (m/s)**	**Arrival Time (ms)**
0.5	229	4.89	0.5	229	9	0.5	229	13	0.5	229	17.6
1.5	97	14.4	1.5	84	20	1.5	79.6	25	1.5	88	28
2.5	113	22.7	2.5	124	27	2.5	111	33	2.5	113	35.8
3.5	120	30.7	3.5	126	34	3.5	137.7	39	3.5	152	41
4.5	112	39.4	4.5	115	42	4.5	123.2	46	4.5	115	48.5
5.5	105	48.8	5.5	106	51	5.5	102.1	55	5.5	105	57
6.5	106	58.1	6.5	107	60	6.5	114.6	63	6.5	117	64.5
7.5	121	66.3	7.5	120	68	7.5	116	71	7.5	119	72
8.5	157	72.6	8.5	159	74	8.5	160	77	8.5	154	77.5
9.5	190	77.8	9.5	190	79	9.5	192.8	81	9.5	200	81.5

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